AL/HR-TR-1995-0107

ARMSTRONG LABORATORY

FLIGHT SIMULATOR VISUAL SYSTEM RESEARCH AND DEVELOPMENT: BIBLIOGRAPHY OF SUPPORT PROVIDED BY THE AIRCREW TRAINING RESEARCH DIVISION

Harold D. Warner

University of Dayton Research Institute
300 College Park Avenue
Dayton, Ohio 45469-0110

Elizabeth P. Casey

HUMAN RESOURCES DIRECTORATE
AIRCREW TRAINING RESEARCH DIVISION
6001 S. Power Road, Bldg 558
Mesa, AZ 85206-0904

July 1995

Final Technical Report for Period March 1995 to June 1995

Approved for public release; distribution is unlimited.

AIR FORCE MATERIEL COMMAND
BROOKS AIR FORCE BASE, TEXAS

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

Elizabeth L. Martin

ELIZABETH L. MARTIN
Project Scientist

Dee H. Andrews

DEE H. ANDREWS
Technical Director

Lynn A. Carroll

LYNN A. CARROLL, Colonel, USAF
Chief, Aircrew Training Research Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
July 1995

3. REPORT TYPE AND DATES COVERED
Final Report - March 1995 to June 1995

4. TITLE AND SUBTITLE
Flight Simulator Visual System Research and Development: Bibliography of Support Provided by the Aircrew Training Research Division

5. FUNDING NUMBERS
C - F33615-90-C-0005
PE - 62205F
PR - 1123
TA - 03, 32
WU - 85, 03

6. AUTHOR(S)
Harold D. Warner
Elizabeth P. Casey

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Dayton Research Institute
300 College Park Avenue
Dayton, OH 45469-0110

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Human Resources Directorate
Aircrew Training Research Division
6001 S. Power Road, Bldg 558
Mesa, AZ 95206-0904

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL/HR-TR-1995-0107

11. SUPPLEMENTARY NOTES
Armstrong Laboratory Technical Monitor: Dr Elizabeth L. Martin, (602) 988-6561

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The present bibliography identifies the technical publications, conference presentations, and journal articles specifically concerning the support of flight simulator visual system research and development (R&D) by the Armstrong Laboratory, Human Resources Directorate, Aircrew Training Research Division (AL/HRA) over the last two decades. (AL/HRA was formerly designated as the Air Force Human Resources Laboratory, Operations Training Division (AFHRL/OT) from 1975 to 1990.) The R&D was conducted by a diverse array of military, government civilian, and contractor personnel, whose expertise encompassed a broad range of disciplines such as visual software development, human factors, aerospace engineering, mathematics, hardware design, computer software development, and visual database modeling. The bibliography is comprised of two sections. The first provides a list of references to the technical publications, conference presentations, and journals categorized according to the subject matter that was addressed; the second section contains an alphabetical listing of the references along with their corresponding abstracts.

14. SUBJECT TERMS
Area of interest; Eye movement; Field of view; Flight simulation; Flight simulators; Head movement; Head-mounted displays; Holographic; Images; Imaging; Motion perception; Simulator sickness; Scene content; Stereoscopic; Variable acuity; Vision; Visual sytem

15. NUMBER OF PAGES
134

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z-39-18
298-102 *COMPUTER GENERATED*

CONTENTS

PREFACE

This bibliography was compiled to highlight the many significant visual simulation system research and development (R&D) accomplishments and contributions of the Armstrong Laboratory, Human Resources Directorate, Aircrew Training Research Division, within the past two decades. Development of the bibliography was supported by the University of Dayton Research Institute, Contract No. F33615-90-C-0005, in conjunction with Work Unit No. 1123-03-85, Flying Training Research Support, and Work Unit No. 1123-32-03, Tactical Scene Content Requirements. The Armstrong Laboratory contract monitor was Ms. Patricia A. Spears; the laboratory technical monitor was Dr Elizabeth L. Martin.

FLIGHT SIMULATOR VISUAL SYSTEM RESEARCH AND DEVELOPMENT: BIBLIOGRAPHY OF SUPPORT PROVIDED BY THE AIRCREW TRAINING RESEARCH DIVISION

INTRODUCTION

For the past 20 years, the Aircrew Training Research Division of Armstrong Laboratory within the Human Resources Directorate (formerly the Operations Training Division of the Air Force Human Resources Laboratory) has supported a variety of flight simulator visual system research and development (R&D) programs. These R&D programs were conducted to provide design specifications and advanced technologies for improving the cuing characteristics of the visual scenes presented in military flight simulators for airborne combat training. A diverse array of military, government civilian, and contractor personnel were involved in the conduct of the programs whose expertise encompassed a broad range of disciplines such as visual psychophysics, human factors, aerospace engineering, mathematics, hardware design, computer software development, and visual database modeling.

The present report is a bibliography of technical publications and conference presentations concerning flight simulator visual system R&D sponsored by the Aircrew Training Research Division. This bibliography is comprised of two sections: Section I is a list of references to the technical publications and conference presentations categorized according to the subject matter that was addressed; Section II is the alphabetical listing of the references along with their corresponding abstracts. References in the first section are partitioned into 35 different subject categories:

1. Visual simulation overview
2. Visual system technologies
3. Helmet-mounted displays
4. Area-of-interest displays
5. Variable-acuity displays
6. Visual system characteristics
7. Visual cue requirements
8. Scene content
9. Visual database development
10. Networked visual simulation
11. Display field of view
12. Scene texture
13. Display color
14. Display luminance
15. Image contrast
16. Display resolution
17. Display collimation
18. Display update rate
19. Display seams and joints
20. Transport delay
21. Video projection
22. Stereoscopic displays
23. Low-altitude flight simulation
24. Aerial refueling simulation
25. Night simulation
26. Eye-movement characteristics
27. Head-movement characteristics
28. Optical flow
29. Human vision characteristics
30. Visual target acquisition
31. Image quality measurement
32. Simulator sickness
33. Simulation evaluation
34. Research requirements
35. IMAGE Conference proceedings

Some of the references were applicable to more than one subject category, for example, display field of view and scene texture. In such cases, the same references were repeated in each of the relevant categories. Overall, 215 different references are contained in the first section. Only technical publications and conference papers approved for public release and unlimited distribution are referenced; distribution-controlled research has been omitted.

The abstracts provided in the second section were edited slightly. Abbreviations (see Appendix) were inserted in some instances in place of frequently used names, and grammatical changes were made to maintain consistency between abstracts. If the author(s) failed to include an abstract in a publication, the absence of the abstract is specified along with the reference in the first section.

SECTION I. REFERENCES

1. VISUAL SIMULATION OVERVIEW

Booth, G. R. (1988). Visual simulation for advanced fighter training. In Proceedings of the 10th Interservice/Industry Training Systems Conference (pp. 108-114). Arlington, VA: National Security Industrial Association.

Cook, P. A. (1982). Aerial combat simulation in the U.S. Air Force. In Proceedings of the AIAA Computer Graphics Symposium, Phoenix Section (AIAA Paper No. 82-3003, pp. 16-19). New York, NY: American Institute of Aeronautics and Astronautics.

Geltmacher, H. E. (1988). Recent advances in computer image generation simulation. Aviation, Space, and Environmental Medicine, 59(11, Suppl.), A39-A45.

Geltmacher, H. E., & Seat, J. C. (1983). Wide field-of-view visual display technology for flight simulation. In Proceedings of the IEEE 1983 National Aerospace and Electronics Conference, NAECON 1983 (Vol. 2, pp. 746-753). New York, NY: Institute of Electrical and Electronics Engineers.

Geltmacher, H., & Thomas, M. (1992). An overview of Air Force combat simulator display development and performance. In J. Morreale (Ed.), 1992 SID International Symposium Digest of Technical Papers, Volume XXIII (pp. 903-905). Playa del Rey, CA: Society for Information Display.

Smith, J. F. (1981). Experience with flight simulators - Training effectiveness and future developments (AFHRL-TP-81-41, AD-A108 087). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Thomas, M., & Geltmacher, H. (1993). Combat simulator display development. Information Display, 9(4 & 5), 23-26.

2. VISUAL SYSTEM TECHNOLOGIES

Cyrus, M. L., & Fogarty, L. (1978). Advanced simulation for new aircraft. In Proceedings of the 11th NTEC/Industry Conference (NAVTRAEQUIPCEN-IH-306, pp. 103-108). Orlando, FL: Naval Training Equipment Center.

Devarajan, V., Hooks, J. T., Jr., & McGuire, D. C. (1984). Low altitude high speed flight simulation using videodisc technology. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 53-65). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Ferguson, R.L. (1984). AVTS: A high fidelity visual simulator. In E.G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 475-486). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Gardner, G.Y., & Rulon, R.S. (1984). Producing high scene content with perspective validity. In E.G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148, pp. 79-94). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory. (No abstract)

Gertner, I. C., Wolberg, G., Geri, G. A., Kelly, G. R., Pierce, B. J., Thomas, M., & Martin, E. L. (1994). A PC-based photographic-quality image generator for flight simulation. In Proceedings of the 16th Interservice/Industry Training Systems and Education Conference (Paper No. 6-1). Arlington, VA: National Security Industrial Association.

Hughes, D. A. (1992). Multiple projector small dome display (AL-TP-1992-0057, AD-A258 621). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Magarinos, J. R., & Coleman, D. J. (1981). Wide angle, color, holographic infinity optics display (AFHRL-TR-80-53, AD A096 890). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Magarinos, J. R., Coleman, D. J., & Lenczowski, T. (1981). Low cost, wide angle infinity optics visual system (AFHRL-TR-80-54, AD-A105 508). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Monroe, E. G. (1975). Computer image generation (CIG) in visual flight simulation. In Proceedings of the Sixth Annual Pittsburgh Conference, Modeling and Simulation, Volume 6, Part 1 (pp. 475-477). Pittsburgh, PA: Instrument Society of America.

Monroe, E. G. (1976). Air-to-surface weapons delivery simulation with a computer-image generation system. In W. G. Vogt & M. H. Mickle (Eds.), Modeling and Simulation, Volume 7, Part 1, Proceedings of the Seventh Annual Pittsburgh Conference (pp. 526-530). Pittsburgh, PA: Instrument Society of America.

Pierce, B. J., Felber, A. A., & Wetzel, P. A. (1993). Real image display effects on oculomotor response and the perception of spatial relationships. In J. Morreale (Ed.), 1993 SID International Symposium Digest of Technical Papers, Volume XXIV (pp. 502-505). Playa del Rey, CA: Society for Information Display.

Platt, P. A., Dahn, D. A., & Amburn, P. (1991). Low-cost approaches to virtual flight simulation. In Proceedings of the IEEE 1991 National Aerospace and Electronics Conference, NAECON 1991 (Vol. 2, pp. 940-946). New York, NY: Institute of Electrical and Electronics Engineers.

Reno, B. (1989). Full field of view dome display system. In AIAA Flight Simulation Technologies Conference and Exhibit, A Collection of Technical Papers (AIAA Paper No. 89-3316, pp. 390-394). Washington, DC: American Institute of Aeronautics and Astronautics.

Thomas, M. L., & Reining, G. (1990). The Display for Advanced Research and Development: An "inexpensive" answer to tactical simulation. In ITEC, International Training Equipment Conference and Exhibition Proceedings (pp. 156-161). Warminster, Wiltshire, UK: ITEC Ltd.

Thomas, M. L., Reining, G., & Kelly, G. (1991). The Display for Advanced Research and Training: An "inexpensive" answer to tactical simulation. In H. M. Assenheim, R. A. Flasck, T. M. Lippert, & J. Bentz (Eds.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1456, Large-Screen-Projection, Avionic, and Helmet-Mounted Displays (pp. 65-75). Bellingham, WA: SPIE-International Society for Optical Engineering.

Thorpe, J. A., Varney, N. C., McFadden, R. W., LeMaster, W. D., & Short, L. H. (1978). Training effectiveness of three types of visual systems for KC-135 flight simulators (AFHRL-TR-78-16, AD A060 253). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Whyte, I., & Zepf, A. W. (1982). Wide-angle, multiviewer, infinity display system (AFHRL-TR-81-27(I), AD-A116 308). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

3. HELMET-MOUNTED DISPLAYS

CAE Electronics Ltd. (1983). Wide-field-of-view, helmet-mounted infinity display system development (AFHRL-TR-84-27, AD-A149 641). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Carey, M. S., Densmore, J. E., Jr., Kerchner, R. M., Lee, A. T., & Hughes, R. (1983). Effects of transport delay on simulator air-to-air engagements (AFHRL-TR-83-8, AD-A133 707). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Dixon, K. W., & Curry, D. G. (1990). Weapons delivery training: Effects of scene content and field of view (AFHRL-TP-88-29, AD-A227 968). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Geri, G. A., & Zeevi, Y. Y. (1985). Visual phenomena produced by binocularly disparate dynamic visual noise (AFHRL-TP-85-4, AD-A154 758). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Hanson, C. L. (1983). Fiber Optic Helmet Mounted Display: A cost effective approach to full visual flight simulation. In Proceedings of the 5th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 262-268). Arlington, VA: American Defense Preparedness Association.

Hanson, C. L., Longridge, T. M., Barrette, R., Welch, B., & Kruk, R. (1984). Fiber-optic helmet-mounted display for full visual flight simulation. In J. Morreale & J. Hammond (Eds.), 1984 SID International Symposium Digest of Technical Papers, Volume XV (pp. 112-115). Los Angeles, CA: Society for Information Display.

Kelly, G., Shenker, M., & Weissman, P. (1992). Helmet-mounted area of interest. In T. M. Lippert (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1695, Helmet-Mounted Displays III (pp. 58-63). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Kelly, G. R., Shenker, M., & Weissman, P. (1992). Helmet-mounted area-of-interest display (AL/HR-TR-1992-0119, AD-A258 275). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Kruk, R., & Longridge, T. M. (1984). Binocular overlap in a fiber optic helmet mounted display. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 363-378). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Kruk, R. V., & Runnings, D. W. (1989). Low level flight performance and air combat maneuvering performance in a simulator with a fiber optic helmet mounted display system. In AIAA Flight Simulation Technologies Conference and Exhibit, A Collection of Technical Papers (AIAA Paper No. 89-3287). Washington, DC: American Institute of Aeronautics and Astronautics.

Leinenwever, R. W., Best, L. G., & Ericksen, B. J. (1992). Low-cost color LCD helmet display. In T. M. Lippert (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1695, Helmet-Mounted Displays III (pp. 68-71). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Leinenwever, R. W., Best, L. G., & Ericksen, B. J. (1992). Low-cost monochrome CRT helmet display. In T. M. Lippert (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1695, Helmet-Mounted Displays III (pp. 64-67). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Leinenwever, R. W., Best, L. G., & Ericksen, B. J. (1993). Low-cost helmet-mounted displays (AL-TR-1993-0008, AD-A262 616). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

List, U. H. (1983). Nonlinear prediction of head movements for helmet-mounted displays (AFHRL-TP-83-45, AD-A136 590). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Longridge, T. M., & Dohme, J. A. (1988). Low cost visual flight simulator testbed. In Proceedings of the 10th Interservice/Industry Training Systems Conference (pp. 372-379). Arlington, VA: National Security Industrial Association.

Longridge, T., Thomas, M., Fernie, A., Williams, T., & Wetzel, P. (1989). Design of an eye slaved area of interest system for the simulator complexity testbed. In Proceedings of the 11th Interservice/Industry Training Systems Conference (pp. 275-283). Arlington, VA: American Defense Preparedness Association.

Robinson, R. M., Thomas, M. L., & Wetzel, P. A. (1989). Eye tracker development on the Fiber Optic Helmet Mounted Display. In J. T. Carollo (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1116, Helmet-Mounted Displays (pp. 102-108). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Thomas, M., Barrette, B., Shenker, M., & Weissman, P. (1989). The enlarged field of view fiber optic helmet mounted display. In AIAA Flight Simulation Technologies Conference and Exhibit, A Collection of Technical Papers (AIAA Paper No. 89-3319, pp. 403-408). Washington, DC: American Institute of Aeronautics and Astronautics.

Thomas, M. L., Robinson, R., Siegmund, W. P., & Antos, S. E. (1990). Fiber optic development for use on the fiber optic helmet-mounted display. Optical Engineering, 29(8), 855-862.

Thomas, M. L., Siegmund, W. P., & Robinson, R. M. (1989). Fiber optic development for use on the Fiber Optic Helmet Mounted Display. In J. T. Carollo (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1116, Helmet-Mounted Displays (pp. 90-101). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Welch, B. L., & Kruk, R. (1986). Engineering and human visual considerations in development of a fibre optic helmet mounted display. In Advances in Flight Simulation - Visual and Motion Systems, International Conference Proceedings (pp. 295-313). London, England: Royal Aeronautical Society.

Welch, B., & Shenker, M. (1984). The Fiber-Optic Helmet-Mounted Display. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 345-361). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Wetzel, P. A., Thomas, M. L., & Williams, T. T. (1990). Development and evaluation of eye tracker performance for use with the Fiber Optic Helmet Mounted Display. In Proceedings of the 12th Interservice/Industry Training Systems Conference (pp. 273-280). Arlington, VA: National Security Industrial Association.

Wetzel, P. A., Thomas, M. L., & Williams, T. T. (1990). Evaluation of eye tracking measurement systems for use with the Fiber Optic Helmet Mounted Display. In H. M. Assenheim & H. H. Bell (Eds.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1289, Cockpit Displays and Visual Simulation (pp. 163-174). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Williams, T., Komoda, M., & Zeevi, J. (1987). Eyetracking with the fiber optic helmet mounted display. In J. Q. B. Chou (Ed.), Proceedings of the 1987 Summer Computer Simulation Conference (pp. 730-734). San Diego, CA: Society for Computer Simulation.

Williams, T., Komoda, M., & Zeevi, J. (1987). Techniques and methods used in eye-tracking in the Fiber-Optic Helmet-Mounted Display. In E. G. Monroe (Ed.), Proceedings of the 1987 IMAGE IV Conference (pp. 314-319). Tempe, AZ: IMAGE Society, Inc.

Woodruff, R. R., Hubbard, D. C., & Shaw, A. (1985). Advanced Simulator for Pilot Training and helmet-mounted visual display configuration comparisons (AFHRL-TR-84-65, AD-A155 326). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Woodruff, R. R., Hubbard, D. C., & Shaw, A. (1986). Comparison of helmet-mounted visual displays for flight simulation. Displays Technology and Applications, 7(4), 179-185.

4. AREA-OF-INTEREST DISPLAYS

Kelly, W. A., & Turnage, G. R. (1977). Area of interest simulation with variable size hood to restrict viewable scene. In E. G. Monroe (Ed.), Proceedings of the 1977 IMAGE Conference (AD-A044 582, pp. 83-105). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Kerchner, R., Lee, A., & Hughes, R. G. (1983). Air combat simulation visual display requirements: An application of engagement simulation modeling (AFHRL-TR-82-39, AD-B072 581). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

LeMaster, W. D., & Longridge, T. M., Jr. (1978). Area of interest/field-of-view research using ASPT (AFHRL-TR-78-11, AD-A055 692). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Longridge, T., Thomas, M., Fernie, A., Williams, T., & Wetzel, P. (1989). Design of an eye slaved area of interest system for the simulator complexity testbed. In Proceedings of the 11th Interservice/Industry Training Systems Conference (pp. 275-283). Arlington, VA: American Defense Preparedness Association.

Monroe, E. G., & Richeson, W. E. (1977). CIG edge conservation evaluation and application to visual flight simulation. In Proceedings of the 10th NTEC/Industry Conference (NAVTRAEQUIPCEN-IH-294, pp. 157-168). Orlando, FL: Naval Training Equipment Center.

Neves, F.B. (1984). Design considerations for an eye-tracked AOI display system, In E.G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 255-266). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory. (No abstract)

Stober, S., Lippay, A., McKinnon, M., Welch, B., & Longridge, T. (1983). A psychophysical evaluation of an area-of-interest (AOI) display. In Proceedings of the Nineteenth Annual Conference on Manual Control (pp. 392-399). Cambridge, MA: Massachusetts Institute of Technology.

Tong, H.J., & Fisher, R.A. (1984). Progress report on an eye-slaved area-of-interest visual display. In E.G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 279-294. Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory. (No abstract)

Warner, H.D. (1981). Effects of reduced visual overlap and field of view on air-to-surface weapons delivery performance (UDR-TR-81-21). Dayton OH: University of Dayton Research Institute.

Warner, H. D., Hubbard, D. C., & Serfoss, G. (1992). Area-of-interest display resolution and stimulus characteristics effects on visual detection thresholds (AL-TR-1991-0134, AD-A247 830). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Warner, H. D., Serfoss, G. L., & Hubbard, D. C. (1993). Effects of area-of-interest display characteristics on visual search performance and head movements in simulated low-level flight (AL-TR-1993-0023, AD-A264 661). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

5. VARIABLE-ACUITY DISPLAYS

Bunker, R. B., & Fisher, R. (1984). Considerations in an optical variable acuity display system. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 239-251). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Geri, G. A. (1991). Psychophysical assessment of wide-field, variable-resolution imagery. In Visual Issues in Training and Simulation Presentation Summaries (pp. 80-82). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory. (No abstract)

Geri, G. A., Zeevi, Y. Y., & Porat, M. (1990). Efficient image generation using localized frequency components matched to human vision (AFHRL-TR-90-25, AD-A224 903). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Geri, G. A., Zeevi, Y. Y., & Vrana, C. A. (1994). Variable-resolution imagery for flight simulation (AL/HR-TR-1993-0180, AD A276 199). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Zeevi, Y. Y., Porat, M., & Geri, G. A. (1990). Computer image generation for flight simulators: The Gabor approach. Visual Computer, 6(2), 93-105.

6. VISUAL SYSTEM CHARACTERISTICS

Kraft, C. L., Anderson, C. D., & Elworth, C. L. (1980). Psychophysical criteria for visual simulation systems (AFHRL-TR-79-30, AD 084 776). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Semple, C. A., Hennessy, R. T., Sanders, M. S., Cross, B. K., Beith, B. H., & McCauley, M. E. (1981). Aircrew training devices: Fidelity features (AFHRL-TR-80-36, AD-A094 665). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Stenger, A. J., Zimmerlin, T. A., Thomas, J. P., & Braunstein, M. (1981). Advanced computer image generation techniques exploiting perceptual characteristics (AFHRL-TR-80-61, AD-A103 365). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Wood, M. E. (1977). The fidelity issue in visual simulation. In E. G. Monroe (Ed.), Proceedings of the 1977 IMAGE Conference (AD-A044 582, pp. 290-295). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory. (No abstract)

7. VISUAL CUE REQUIREMENTS

Coward, R. E., & Rupp, A. M. (1982). Simulator for Air-to-Air Combat versus real world: Visual cue analysis for simulated air-to-air combat training (AFHRL-TR-81-26, AD-A110 570). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Farrell, R., & Barker, R. (1983). Integrated cuing requirements (ICR) study: Feasibility analysis and demonstration study (AFHRL-TP-82-25(I), AD-A131 019). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Farrell, R., & Barker, R. (1983). Integrated cuing requirements (ICR) study: Demonstration data base and users guide (AFHRL-TP-82-25(II), AD-A131 019). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Gardner, G.Y., & Rulon, R.S. (1984). Producing high scene content with perspective validity. In E.G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 79-94). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory. (No abstract)

Gray, T. H. (1982). Manual reversion flight control system for A-10 aircraft: Pilot performance and simulator cue effects (AFHRL-TR-81-53, AD-A113 463). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Harker, G. S., & Jones, P. D. (1980). Depth perception in visual simulation (AFHRL-TR-80-19, AD-A087 828). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Kerchner, R. M., Hughes, R. G., & Lee, A. T. (1983). TAC BRAWLER: An application of engagement simulation modeling to simulator visual system display requirements for air combat maneuvering. In Proceedings of the International Conference on Simulators (pp. 110-114). London, England: Institution of Electrical Engineers.

Semple, C. A., Hennessy, R. T., Sanders, M. S., Cross, B. K., Beith, B. H., & McCauley, M. E. (1981). Aircrew training devices: Fidelity features (AFHRL-TR-80-36, AD-A094 665). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Warner, H. D. (1988). Task listing: Visually assisted and visually dependent tasks for fighter aircraft (AFHRL-TP-87-55, AD-A191 041). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Warner, H. D., Serfoss, G., & Hubbard, D. C. (1991). Target identification requirements in tactical simulators. In Visual Issues in Training and Simulation Presentation Summaries (pp. 70-74). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Warner, H. D., Serfoss, G. L., & Hubbard, D. C. (1993). Visual cue requirements for target orientation assessment in air combat simulation (AL-TR-1993-0021, AD-A262 575). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

8. SCENE CONTENT

Buckland, G. H. (1980). Visual cue requirements for terrain flight simulation. In Proceedings of the 2nd Interservice/Industry Training Equipment Conference and Exhibition (pp. 92-93). Arlington, VA: National Security Industrial Association.

Buckland, G. H., Edwards, B. J., & Stephens, C. W. (1981). Flight simulator visual and instructional features for terrain flight simulation. In E. G. Monroe (Ed.), Proceedings of the 1981 IMAGE II Conference (AFHRL-TR-81-48, AD-A110 226, pp. 350-362). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

De Maio, J., Bell, H. H., & Brunderman, J. (1985). Pilot-oriented performance measurement (AFHRL-TP-85-18, AD-A158 849). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

De Maio, J., & Brooks, R. (1982). Assessment of simulator visual cueing effectiveness by psychophysical techniques. In Proceedings of the 4th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 379-381). Arlington, VA: National Security Industrial Association.

De Maio, J., Brooks, R., Brunderman, J., & Rinalducci, E. J. (1983). Visual cueing effectiveness - Comparison of perception and flying performance. In A. T. Pope & L. D. Haugh (Eds.), Proceedings of the Human Factors Society 27th Annual Meeting (Vol. 2, pp. 928-932). Santa Monica, CA: Human Factors Society.

De Maio, J., Rinalducci, E. J., Brooks, R., & Brunderman, J. (1983). Visual cueing effectiveness: Comparison of perception and flying performance. In Proceedings of the 5th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 92-96). Arlington, VA: American Defense Preparedness Association.

Dixon, K. W., & Curry, D. G. (1987). Effect of scene content and field of view on weapons delivery training. In Proceedings of the 9th Interservice/Industry Training Systems Conference (pp. 247-256). Arlington, VA: American Defense Preparedness Association.

Dixon, K. W., & Curry, D. G. (1990). Weapons delivery training: Effects of scene content and field of view (AFHRL-TP-88-29, AD-A227 968). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Irish, P. A., III, & Buckland, G. H. (1978). Effects of platform motion, visual and G-seat factors upon experienced pilot performance in the flight simulator (AFHRL-TR-78-9, AD-A055 691). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Kleiss, J. A. (1990). Terrain visual cue analysis for simulating low-level flight: A multidimensional scaling approach (AFHRL-TR-90-20, AD-A223 564). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Kleiss, J. A. (1990). Terrain visual cue analysis for simulating low-level flight: A multidimensional scaling approach. In E. G. Monroe (Ed.), Proceedings of the 1990 IMAGE V Conference (pp. 60-67). Tempe, AZ: IMAGE Society, Inc.

Kleiss, J. A. (1991). Cuing and scene content requirements for low-level flight. In Visual Issues in Training and Simulation Presentation Summaries (pp. 31-32). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory. (No abstract)

Kleiss, J. A. (1991). Multidimensional scaling analysis of terrain features relevant for simulating low-altitude flight. In Proceedings of the Human Factors Society 35th Annual Meeting (Vol. 2, pp. 1372-1376). Santa Monica, CA: Human Factors Society.

Kleiss, J. A. (1992). Influence of operational factors on importance of scene properties for visual low-altitude flight (AL-TR-1992-0158). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Kleiss, J. A. (1992). Perceptual dimensions of visual scenes relevant for simulating low-altitude flight (AL-TR-1992-0011, AD-A254 645). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Kleiss, J. A. (1992). Tradeoffs among types of scene detail for simulating low-altitude flight. In Proceedings of the 1992 IEEE International Conference on Systems, Man, and Cybernetics (Vol. 2, pp. 1141-1146). New York, NY: Institute of Electrical and Electronics Engineers.

Kleiss, J. A. (1993). Properties of computer-generated scenes important for simulating low altitude flight. In Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting (Vol. 1, pp. 98-102). Santa Monica, CA: Human Factors and Ergonomics Society.

Kleiss, J. A. (1994). Effect of terrain shape and object grouping on detection of altitude change in a flight simulator. In Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting (Vol. 1, pp. 119-123). Santa Monica, CA: Human Factors and Ergonomics Society.

Kleiss, J. A., Curry, D. G., & Hubbard, D. C. (1988). Effect of three-dimensional object type and density in simulated low- level flight. In Proceedings of the Human Factors Society 32nd Annual Meeting (Vol. 2, pp. 1299-1303). Santa Monica, CA: Human Factors Society.

Kleiss, J. A., Curry, D. G., & Hubbard, D. C. (1989). Effect of three-dimensional object type and density in simulated low-level flight (AFHRL-TR-88-66, AD-A209 756). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Kleiss, J. A., & Hubbard, D. C. (1991). Effect of two types of scene detail on detection of altitude change in a flight simulator (AL-TR-1991-0043, AD-A242 034). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Kleiss, J. A., & Hubbard, D. C. (1993). Effects of three types of flight simulator visual scene detail on detection of altitude change. Human Factors, 35(4), 653-671.

Martin, E. L., & Rinalducci, E. J. (1983). Low-level flight simulation: Vertical cues (AFHRL-TR-83-17, AD-A133 612). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

McCormick, D., Smith, T., Lewandowski, F., Preskar, W., & Martin, E. (1983). Low-Altitude Database Development Evaluation and Research (LADDER). In Proceedings of the 5th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 150-155). Arlington, VA: American Defense Preparedness Association.

Rinalducci, E. J., De Maio, J., Patterson, M. J., & Brooks, R. (1983). Psychophysical assessment of simulator visual displays. In R. S. Jensen (Ed.), Proceedings of the Second Symposium on Aviation Psychology (pp. 489-494). Columbus, OH: Ohio State University.

Rinalducci, E. J., Martin, E. L., & Longridge, T. (1982). Visual cues in the simulation of low level flight. In J. F. Swiney, Jr. (Ed.), Proceedings of the Eighth Symposium on Psychology in the Department of Defense (ASAFA-TR-82-10, pp. 32-36). Colorado Springs, CO: Department of Behavioral Sciences and Leadership, U.S. Air Force Academy.

Rinalducci, E. J., Patterson, M. J., & De Maio, J. (1984). Static vs. dynamic presentation of visual cues in simulated low level flight. In Proceedings of the Ninth Symposium Psychology in the Department of Defense (USAFA-TR-84-2, AD-A141 043, pp. 667-671). Colorado Springs, CO: Department of Behavioral Sciences and Leadership, U.S. Air Force Academy.

9. VISUAL DATABASE DEVELOPMENT

Kellogg, R. S., Prather, D. C., & Castore, C. H. (1980). Simulated A-10 combat environment. In G. E. Corrick, E. C. Haseltine, & R. T. Durst, Jr. (Eds.), Proceedings of the Human Factors Society 24th Annual Meeting (pp. 573-577). Santa Monica, CA: Human Factors Society.

Kellogg, R. S., Prather, D. C., & Castore, C. N. (1981). Simulated A-10 combat environment. In E. G. Monroe (Ed.), Proceedings of the 1981 IMAGE II Conference (AFHRL-TR-81-48, AD-A110 226, pp. 35-44). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Miller, R. H. (1978). Advanced Simulator for Pilot Training (ASPT): Refinement of environmental database generation system (AFHRL-TR-78-55, AD-A059 857). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Monroe, E. G. (1975). Environmental data base development process for the ASUPT CIG system (AFHRL-TR-75-24, AD-A017 845). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Monroe, E. G. (1976). Air-to-surface full mission simulation by the ASUPT system. In Proceedings of the 9th NTEC/Industry Conference (NAVTRAEQUIPCEN-IH-276, pp. 41-48). Orlando, FL: Naval Training Equipment Center.

Monroe, E. G. (1976). Air-to-surface full mission simulation by the ASUPT system. In Proceedings of the 9th NTEC/Industry Conference (NAVTRAEQUIPCEN-IH-276, pp. 41-48). Orlando, FL: Naval Training Equipment Center.

Monroe, E. G., Rife, R. W., Cyrus, M. L., & Thompson, L. C. (1976). ASUPT visual simulation of air-to-surface weapons delivery (AFHRL-TR-76-40, AD-A034 319). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Rife, R. W. (1977). Level-of-detail control considerations for CIG systems. In E. G. Monroe (Ed.), Proceedings of the 1977 IMAGE Conference (AD-A044 582, pp. 142-159). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Stephens, C. W., Dickens, T. M., Widder, P. A., & Sheen, R. L. (1982). Red Flag simulation: Development of an interactive, high threat combat environment. In Proceedings of the 4th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 459-465). Arlington, VA: National Security Industrial Association.

Widder, P. A., & Stephens, C. W. (1983). Data base generation: Improving the state-of-the-art. In Proceedings of the 5th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 164-170). Arlington, VA: American Defense Preparedness Association.

10. NETWORKED VISUAL SIMULATION

Malone, H. L., III, Horowitz, S., Brunderman, J. A., & Eulenbach, H. (1987). The impact of network delay on two-ship air-to-air combat simulation. In AIAA Flight Simulation Technologies Conference, A Collection of Technical Papers (AIAA Paper No. 87-2373, pp. 55-58). New York, NY: American Institute of Aeronautics and Astronautics.

McCollough-Howard, C. (1993). Device-independent color rendering for multiple display devices and networked simulator displays. In J. Morreale (Ed.), 1993 SID International Symposium Digest of Technical Papers, Volume XXIV (pp. 569-572). Playa del Rey, CA: Society for Information Display.

Moran, S. I., & Kornovich, W. M., Jr. (1992). Advanced network technologies for visual research. In E. G. Monroe (Ed.), Proceedings of the 1992 IMAGE VI Conference (pp. 114-121). Tempe, AZ: IMAGE Society, Inc.

Thomas, M. L., Martin, E., & Serfoss, G. (1992). Low cost portable display development and evaluation for distributed interactive tactical simulators. In Proceedings of the Twelfth International Display Research Conference, Japan Display '92 (pp. 669-672). Playa del Rey, CA: Society for Information Display; Tokyo, Japan: Institute of Television Engineers of Japan.

11. DISPLAY FIELD OF VIEW

Collyer, S. C., Ricard, G. L., Anderson, M., Westra, D. P., & Perry, R. A. (1980). Field of view requirements for carrier landing training (NAVTRAEQUIPCEN-IH-319/AFHRL-TR-80-10, AD-A088 701). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory; Orlando, FL: Naval Training Equipment Center.

Dixon, K. W., & Curry, D. G. (1987). Effect of scene content and field of view on weapons delivery training. In Proceedings of the 9th Interservice/Industry Training Systems Conference (pp. 247-256). Arlington, VA: American Defense Preparedness Association.

Dixon, K. W., & Curry, D. G. (1990). Weapons delivery training: Effects of scene content and field of view (AFHRL-TP-88-29, AD-A227 968). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Dixon, K. W., Krueger, G. M., Rojas, V. A., & Hubbard, D. C. (1989). The effect of instantaneous field of view size on the acquisition of low level flight and 30-degree manual dive bombing tasks. In J. T. Carollo (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1116, Helmet-Mounted Displays (pp. 110-121). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Dixon, K. W., Krueger, G. M., Rojas, V. A., & Martin, E. L. (1990). Visual behavior in the F-15 Simulator for Air-to-Air Combat (AFHRL-TP-89-75, AD-A218 648). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Dixon, K. W., Martin, E. L., & Krueger, G. M. (1989). The effect of stationary and head-driven field-of-view sizes on pop-up weapons delivery. In Proceedings of the 11th Interservice/Industry Training Systems Conference (pp. 137-141). Arlington, VA: American Defense Preparedness Association.

Dixon, K. W., Martin, E. L., & Krueger, G. M. (1990). Effects of field-of-view sizes on pop-up weapons delivery (AFHRL-TR-89-51, AD-A223 018). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Dixon, K. W., Martin, E. L., Krueger, G. M., & Rojas, V. A. (1989). Eye movement in air-to-air combat tasks. In AIAA Flight Simulation Technologies Conference and Exhibit, A Collection of Technical Papers (AIAA Paper No. 89-3323, pp. 422-425). Washington, DC: American Institute of Aeronautics and Astronautics.

Dixon, K. W., Martin, E. L., Rojas, V. A., & Hubbard, D. C. (1988). The effects of field-of-view on pilot performance in the C-130 WST. In Proceedings of the 10th Interservice/Industry Training Systems Conference (pp. 362-371). Arlington, VA: National Security Industrial Association.

Dixon, K. W., Martin, E. L., Rojas, V. A., & Hubbard, D. C. (1990). Field-of-view assessment of low-level flight and an airdrop in the C-130 Weapon System Trainer (WST) (AFHRL-TR-89-9, AD-A218 504). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Irish, P. A., III, & Buckland, G. H. (1978). Effects of platform motion, visual and G-seat factors upon experienced pilot performance in the flight simulator (AFHRL-TR-78-9, AD-A055 691). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Irish, P. A., III, Grunzke, P. M., Gray, T. H., & Waters, B. K. (1977). The effects of system and environmental factors upon experienced pilot performance in the Advanced Simulator for Pilot Training (AFHRL-TR-77-13, AD-A043 195). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Kellogg, R. S., Hubbard, D. C., & Sieverding, M. J. (1989). Field-of-view variations and stripe-texturing effects on assault landing performance in the C-130 Weapon System Trainer (AFHRL-TR-89-3, AD-A212 763). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Kerchner, R. M., Hughes, R. G., & Lee, A. (1983). TAC BRAWLER: An application of engagement simulation modeling to simulator visual system display requirements for air combat maneuvering. In R. S. Jensen (Ed.), Proceedings of the Second Symposium on Aviation Psychology (pp. 599-606). Columbus, OH: Ohio State University.

Kerchner, R., Lee, A., & Hughes, R. G. (1983). Air combat simulation visual display requirements: An application of engagement simulation modeling (AFHRL-TR-82-39, AD-B072 581). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Nataupsky, M., Waag, W. L., Weyer, D. C., McFadden, R. W., & McDowell, E. (1979). Platform motion contributions to simulator training effectiveness: Study III - Interaction of motion with field-of-view (AFHRL-TR-79-25, AD-A078 426). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Waters, B. K., Grunzke, P. M., Irish, P. A., III, & Fuller, J. H., Jr. (1976). Preliminary investigation of motion, visual and G-seat effects in the Advanced Simulator for Undergraduate Pilot Training (ASUPT). In AIAA Visual and Motion Simulation Conference. Washington, DC: American Institute of Aeronautics and Astronautics.

Wiekhorst, L. A., & Vaccaro, F. T. (1988). Flight simulator: Field of view utilized in performing tactical maneuvers (AFHRL-TP-87-50, AD-A192 412). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Woodruff, R. R., Hubbard, D. C., & Shaw, A. (1985). Advanced Simulator for Pilot Training and helmet-mounted visual display configuration comparisons (AFHRL-TR-84-65, AD-A155 326). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Woodruff, R. R., Hubbard, D. C., & Shaw, A. (1986). Comparison of helmet-mounted visual displays for flight simulation. Displays Technology and Applications, 7(4), 179-185.

Woodruff, R. R., Longridge, T. M., Jr., Irish, P. A., III, & Jeffreys, R. T. (1979). Pilot performance in simulated aerial refueling as a function of tanker model complexity and visual display field-of-view (AFHRL-TR-78-98, AD-A070 231). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

12. SCENE TEXTURE

Buckland, G. H. (1980). Flight simulator runway visual textural cues for landing. In G. E. Corrick, E. C. Haseltine, & R. T. Durst, Jr. (Eds.), Proceedings of the Human Factors Society 24th Annual Meeting (pp. 286-287). Santa Monica, CA: Human Factors Society.

Buckland, G. H. (1980). Visual cue requirements for terrain flight simulation. In Proceedings of the 2nd Interservice/Industry Training Equipment Conference and Exhibition (pp. 92-93). Arlington, VA: National Security Industrial Association.

Buckland, G. H., Edwards, B. J., & Stephens, C. W. (1981). Flight simulator visual and instructional features for terrain flight simulation. In E. G. Monroe (Ed.), Proceedings of the 1981 IMAGE II Conference (AFHRL-TR-81-48, AD-A110 226, pp. 350-362). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Buckland, G. H., Monroe, E. G., & Mehrer, K. I. (1977). Simulator runway touchdown zone visual requirements; textural visual cue considerations. In E. G. Monroe (Ed.), Proceedings of the 1977 IMAGE Conference (AD-A044 582, pp. 174-184). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Buckland, G. H., Monroe, E. G., & Mehrer, K. I. (1980). Flight simulator runway visual textural cues for landing (AFHRL-TR-79-81, AD-A089 434). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

De Maio, J., & Brooks, R. (1985). Perception of altitude in the low and medium altitude ranges. In R. S. Jensen & J. Adrion (Eds.), Proceedings of the Third Symposium on Aviation Psychology (pp. 505-512). Columbus, OH: Ohio State University.

deSpautz, J. F., Bender, M. B., & McNamara, V. M. (1980). Flight training simulator: Surface texturing via pseudo random noise codes (AFHRL-TR-80-13, AD-A093 734). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Geri, G. A., Lyon, D. R., & Zeevi, Y. Y. (1994). Visual evaluation of computer-generated textures (AL/HR-TR-1993-0189, AD-A277 201). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Kellogg, R. S., Hubbard, D. C., & Sieverding, M. J. (1989). Field-of-view variations and stripe-texturing effects on assault landing performance in the C-130 Weapon System Trainer (AFHRL-TR-89-3, AD-A212 763). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Kleiss, J. A. (1994). Effect of terrain shape and object grouping on detection of altitude change in a flight simulator. In Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting (Vol. 1, pp. 119-123). Santa Monica, CA: Human Factors and Ergonomics Society.

McCormick, D., Smith, T., Lewandowski, F., Preskar, W., & Martin, E. (1983). Low-Altitude Database Development Evaluation and Research (LADDER). In Proceedings of the 5th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 150-155). Arlington, VA: American Defense Preparedness Association.

Owen, D. H. (1985). Optical and event-duration variables affecting self-motion perception (AFHRL-TP-85-23, AD-A161 836). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Owen, D. H.; Freeman, S. J.; Zaff, B. F.; & Wolpert, L. (1987). Perception and control of simulated self motion (AFHRL-TR-87-16, AD A187 4444). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Phelps, M. (1984). Low altitude texture comparison data base and smooth shaded texture (AFHRL-TP-84-33, AD-A150 342). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Serreyn, D., & Duncan, D. (1981). Computer image generation: Advanced visual/sensor simulation (AFHRL-TP-81-23, AD-A107 098). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Soland, D., Voth, M., & Narendra, P. M. (1981). Real-time feasibility for generation of nonlinear textured terrain (AFHRL-TR-79-27, AD-A095 070). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Warner, H.D., Serfoss, G.L., & Hubbard, D.C. (1994). Altitude cuing effectiveness of terrain texture characteristics in simulated low-altitude flight (AL/HR-TR-1994-0168, AD A294 369). Mesa, AZ: Aircrew Training Research Division, Armstrong Laboratory.

13. DISPLAY COLOR

Garrett, J. L., Hepner, J. W., & Howard, C. M. (1993). Color control for flight simulation at Armstrong Laboratory. In R. J. Motta & H. A. Berberian (Eds.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1909, Device-Independent Color Imaging and Imaging Systems Integration (pp. 206-211). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Howard, C. M. (1990). An automated method of device-independent color rendering. In E. G. Monroe (Ed.), Proceedings of the 1990 IMAGE V Conference (pp. 270-273). Tempe, AZ: IMAGE Society, Inc.

Howard, C. M. (1991). Control and use of color in flight simulators. In Visual Issues in Training and Simulation Presentation Summaries (pp. 97-101). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory. (No abstract)

Howard, C. M. (1994). Color control in a multichannel simulator display: The Display for Advanced Research and Training (AL/HR-TR-1994-0024, AD-A279 717). Mesa, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Howard, C. M., & Burnidge, J. (1994). Colors in natural landscapes (AL/HR-TR-1993-0172, AD-A277 204). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Howard, C. M., & Burnidge, J. A. (1994). Colors in natural landscapes. Journal of the Society for Information Display, 2(1), 47-55.

Kellogg, R. S., Kennedy, R. S., & Woodruff, R. R. (1983). Comparison of colour and black-and-white visual displays as indicated by bombing performance in the 2B35 TA-4J flight simulator. Displays Technology and Applications, 4(2), 106-107.

Kellogg, R. S., Kennedy, R. S., & Woodruff, R. R. (1984). Comparison of color versus black-and-white visual displays as indicated by bombing and landing performance in the 2B35 TA-4J flight simulator (AFHRL-TR-84-22, AD-A144 674). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

McCollough-Howard, C. (1992). Color control in digital displays. In M. A. Karim (Ed.), Electro-Optical Displays (pp. 711-742). New York, NY: Marcel Dekker, Inc. (No abstract)

McCollough-Howard, C. (1993). Device-independent color rendering for multiple display devices and networked simulator displays. In J. Morreale (Ed.), 1993 SID International Symposium Digest of Technical Papers, Volume XXIV (pp. 569-572). Playa del Rey, CA: Society for Information Display.

Woodruff, R. R. (1979). Effects of varying visual display characteristics of the T-4G, a T-37 flight simulator (AFHRL-TR-79-17, AD-A071 410). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

14. DISPLAY LUMINANCE

Evans, R. J. (1994). Empirical approach to visual display preference based upon modulation transfer function and luminance (AL/HR-TR-1994-0107, AD-A285 450). Mesa, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Howard, C. M. (1990). Measurement of apparent brightness in the mesopic luminance range. In M. H. Brill (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1250, Perceiving, Measuring, and Using Color (pp. 19-25). Bellingham, WA: SPIE-The International Society for Optical Engineering.

15. IMAGE CONTRAST

Kerchner, R. M., Hughes, R. G., & Lee, A. (1983). TAC BRAWLER: An application of engagement simulation modeling to simulator visual system display requirements for air combat maneuvering. In R. S. Jensen (Ed.), Proceedings of the Second Symposium on Aviation Psychology (pp. 599-606). Columbus, OH: Ohio State University.

Kerchner, R., Lee, A., & Hughes, R. G. (1983). Air combat simulation visual display requirements: An application of engagement simulation modeling (AFHRL-TR-82-39, AD-B072 581). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Lee, A. T., & Hughes, R. G. (1981). Visual display resolution and contrast requirements for air combat simulation: An application of computer modeling. In Proceedings of the 3rd Interservice/Industry Training Equipment Conference and Exhibition (Vol. 1, pp. 33-40). Arlington, VA: American Defense Preparedness Association.

16. DISPLAY RESOLUTION

Kerchner, R. M., Hughes, R. G., & Lee, A. (1983). TAC BRAWLER: An application of engagement simulation modeling to simulator visual system display requirements for air combat maneuvering. In R. S. Jensen (Ed.), Proceedings of the Second Symposium on Aviation Psychology (pp. 599-606). Columbus, OH: Ohio State University.

Kerchner, R., Lee, A., & Hughes, R. G. (1983). Air combat simulation visual display requirements: An application of engagement simulation modeling (AFHRL-TR-82-39, AD-B072 581). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Lee, A. T., & Hughes, R. G. (1981). Visual display resolution and contrast requirements for air combat simulation: An application of computer modeling. In Proceedings of the 3rd Interservice/Industry Training Equipment Conference and Exhibition (Vol. 1, pp. 33-40). Arlington, VA: American Defense Preparedness Association.

17. DISPLAY COLLIMATION

Bell, H. H., & Cuiffreda, K. J. (1985). Effects of collimation on accommodation and vergence in the Advanced Simulator for Pilot Training (AFHRL-TP-85-27, AD-A159 545). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Woodruff, R. R. (1979). Effects of varying visual display characteristics of the T-4G, a T-37 flight simulator (AFHRL-TR-79-17, AD-A071 410). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

18. DISPLAY UPDATE RATE

Lindholm, J. M. (1991). Determinants and consequences of smooth pursuit. In Visual Issues in Training and Simulation Presentation Summaries (pp. 102-106). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory. (No abstract)

Lindholm, J. M. (1992). Perceptual effects of spatiotemporal sampling. In M. A. Karim (Ed.), Electro-optical displays (pp. 787-808). New York, NY: Marcel Dekker, Inc. (No abstract)

Lindholm, J. M. (1992). Temporal and spatial factors affecting the perception of computer-generated imagery (AL-TR-1991-0140, AD-A249 242). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Lindholm, J. M., Askins, T. M., & Krasnicka, K. (1993). Image update rate and apparent self-motion speed. In J. Morreale (Ed.), 1993 SID International Symposium Digest of Technical Papers, Volume XXIV (pp. 506-509). Playa del Rey, CA: Society for Information Display.

Lindholm, J. M., & Martin, E. L. (1993). Effect of image update rate on moving target identification range (AL-TR-1992-0172, AD-A261 562). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Martin, E. L., & Lindholm, J. M. (1992). Effects of image update rate on target identification range. In Proceedings of the Thirteenth Symposium Psychology in the Department of Defense (USAFA TR 92-2, pp. 178-182). Colorado Springs, CO: Department of Behavioral Sciences and Leadership, U.S. Air Force Academy.

19. DISPLAY SEAMS AND JOINTS

Kraft, C. L., & Anderson, C. D. (1980). Psychophysical criteria for visual simulations systems: Phase II - Experimental investigations of display joints and scene inserts (AFHRL-TR-80-18, AD-A088 316). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

20. TRANSPORT DELAY

Carey, M. S., Densmore, J. E., Jr., Kerchner, R. M., Lee, A. T., & Hughes, R. (1983). Effects of transport delay on simulator air-to-air engagements (AFHRL-TR-83-8, AD-A133 707). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Cyrus, M. L. (1977). Method for compensating transport lags in computer image generation visual displays for flight simulation (AFHRL-TR-77-6, AD-A040 551). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Horowitz, S. J. (1986). Measurements and effects of transport delays in a state-of-the-art F-16C flight simulator. In Proceedings of the 8th Interservice/Industry Training Systems Conference (Vol. 1, pp. 316-321). Arlington, VA: National Security Industrial Association.

Horowitz, S. J. (1987). Measurement and effects of transport delays in a state-of-the-art F-16C flight simulator (AFHRL-TP-87-11, AD-A187 367). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Kerchner, R. M., Hughes, R. G., & Lee, A. (1983). TAC BRAWLER: An application of engagement simulation modeling to simulator visual system display requirements for air combat maneuvering. In R. S. Jensen (Ed.), Proceedings of the Second Symposium on Aviation Psychology (pp. 599-606). Columbus, OH: Ohio State University.

Leinenwever, R. W., & Moran, S. I. (1992). Transport delay measurements: Methodology and analysis for the F-16C Combat Engagement Trainer, the Display for Advanced Research and Training, and the F-16A Limited Field of View (AL-TP-1992-0009, AD-A248 519). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Malone, H. L., III, Horowitz, S., Brunderman, J. A., & Eulenbach, H. (1987). The impact of network delay on two-ship air-to-air combat simulation. In AIAA Flight Simulation Technologies Conference, A Collection of Technical Papers (AIAA Paper No. 87-2373, pp. 55-58). New York, NY: American Institute of Aeronautics and Astronautics.

Ricard, G. L., Cyrus, M. L., Cox, D. C., Templeton, T. K., & Thompson, L. C. (1978). Compensation for transport delays produced by computer image generation systems (NAVTRAEQUIPCEN-IH-297, AFHRL-TR-78-46, AD-A056 720). Orlando, FL: Naval Training Equipment Center; Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

21. VIDEO PROJECTION

Baron, P.C., Efron, U., & Grinberg, J. (1981). Project 2363: Liquid crystal light valve projector investigations. In E.G. Monroe (Ed.), Proceedings of the 1981 IMAGE II Conference (AFHRL-TR-81-48, AD A110 226), pp. 198-219). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory. (No abstract)

Crane, P. M., Gerlicher, J. P., & Bell, H. H. (1986). Flight simulator: Comparison of resolution thresholds for two light valve video projectors (AFHRL-TP-85-43, AD-A164 577). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Efron, U., Grinberg, J., Reif, P. G., & Braatz, P. (1981). Silicon liquid crystal light valve for flight simulation applications (AFHRL-TR-81-35, AD-A110 928). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Gerlicher, J. P. (1985). Flight simulator: Evaluation of SODERN Visualization System SVS-14 (AFHRL-TP-85-11, AD-A161 794). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Howard, C. M. (1989). Color performance of light-valve projectors. In F. J. Kahn (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1081, Projection Display Technology, Systems, and Applications (pp. 107-114). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Howard, C. M. (1989). Display characteristics of example light-valve projectors (AFHRL-TR-88-44, AD-A209 580). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Lindenberg, K. W. (1982). Color television projection system using three cathode ray tubes (AFHRL-TP-82-5, AD-A114 828). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

McCollough-Howard, C. (1993). Device-independent color rendering for multiple display devices and networked simulator displays. In J. Morreale (Ed.), 1993 SID International Symposium Digest of Technical Papers, Volume XXIV (pp. 569-572). Playa del Rey, CA: Society for Information Display.

Peppler, P. W., & Gainer, J. C. (1993). A full-color, high-resolution laser projector for a flight simulator visual display (AL-TR-1993-0120, AD-A270 578). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Peppler, P. W., & Gainer, J. C. (1994). A full-color, high-resolution laser projector for a flight simulator visual display. In N. Jackson & N. Cruz (Eds.), 5th ITEC, International Training Equipment Conference and Exhibition Proceedings (pp. 112-129). Warminster, Wiltshire, UK: ITEC Ltd.

Sisson, N., Howard, C., & Pierce, B. (1993). Prediction of light-valve color output. In J. Morreale (Ed.), 1993 SID International Symposium Digest of Technical Papers, Volume XXIV (pp. 137-140). Playa del Rey, CA: Society for Information Display.

22. STEREOSCOPIC DISPLAYS

Woodruff, R. R., Hubbard, D. C., & Shaw, A. (1985). Advanced Simulator for Pilot Training and helmet-mounted visual display configuration comparisons (AFHRL-TR-84-65, AD-A155 326). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

23. LOW-ALTITUDE FLIGHT SIMULATION

Edwards, B. J., Pohlman, D. L., Buckland, G. H., & Stephens, C. W. (1981). Training low level terrain flight in a simulator. In Proceedings of the 3rd Interservice/Industry Training Equipment Conference and Exhibition (Vol. 1, pp. 56-61). Arlington, VA: American Defense Preparedness Association.

Kellogg, R. S., & Miller, M. (1984). Visual perceptual aspects of low level high speed flight and flight simulation. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 21-35). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Miller, M. (1984). Using a limited field of view simulator to instruct high speed, low altitude flying skills. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 7-20). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

24. AERIAL REFUELING SIMULATION

Lee, A. T., & Lidderdale, I. G. (1983). Visual scene simulation requirements for C-5A/C-141B Aerial Refueling Part Task Trainer (AFHRL-TP-82-34, AD-A128 769). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Monroe, E. G., Mehrer, K. I., Engel, R. L., Hannan, S., McHugh, J., Turnage, G., & Lee, D. R. (1978). Advanced Simulator for Pilot Training (ASPT): Aerial refueling visual simulation - engineering development (AFHRL-TR-78-51, AD-A063 283). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Woodruff, R. R., Hubbard, D. C., & Shaw, A. (1985). Advanced Simulator for Pilot Training and helmet-mounted visual display configuration comparisons (AFHRL-TR-84-65, AD-A155 326). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Woodruff, R. R., Hubbard, D. C., & Shaw, A. (1986). Comparison of helmet-mounted visual displays for flight simulation. Displays Technology and Applications, 7(4), 179-185.

Woodruff, R. R., Longridge, T. M., Jr., Irish, P. A., III, & Jeffreys, R. T. (1979). Pilot performance in simulated aerial refueling as a function of tanker model complexity and visual display field-of-view (AFHRL-TR-78-98, AD-A070 231). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

25. NIGHT SIMULATION

Buckland, G. H. (1980). Flight simulator runway visual textural cues for landing. In G. E. Corrick, E. C. Haseltine, & R. T. Durst, Jr. (Eds.), Proceedings of the Human Factors Society 24th Annual Meeting (pp. 286-287). Santa Monica, CA: Human Factors Society.

Buckland, G. H., Edwards, B. J., & Stephens, C. W. (1981). Flight simulator visual and instructional features for terrain flight simulation. In E. G. Monroe (Ed.), Proceedings of the 1981 IMAGE II Conference (AFHRL-TR-81-48, AD-A110 226, pp. 350-362). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Buckland, G. H., Monroe, E. G., & Mehrer, K. I. (1980). Flight simulator runway visual textural cues for landing (AFHRL-TR-79-81, AD-A089 434). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Martin, E. L., & Cataneo, D. F. (1980). Computer generated image: Relative training effectiveness of day versus night visual scenes (AFHRL-TR-79-56, AD-A088 313). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Thorpe, J. A., Varney, N. C., McFadden, R. W., LeMaster, W. D., & Short, L. H. (1978). Training effectiveness of three types of visual systems for KC-135 flight simulators (AFHRL-TR-78-16, AD-A060 253). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

26. EYE-MOVEMENT CHARACTERISTICS

Daum, K. M. (1991). The eye movement behavior of pilots. In Visual Issues in Training and Simulation Presentation Summaries (pp. 90-94). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Dixon, K. W., Krueger, G. M., & Rojas, V. A. (1988). The use of an eye-tracking device for the measurement of flight performance in simulators. In AIAA Flight Simulation Technologies Conference, A Collection of Technical Papers (AIAA Paper No. 88-4613, pp. 222-225). Washington, DC: American Institute of Aeronautics and Astronautics.

Dixon, K. W., Krueger, G. M., Rojas, V. A., & Martin, E. L. (1990). Visual behavior in the F-15 Simulator for Air-to-Air Combat (AFHRL-TP-89-75, AD-A218 648). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Dixon, K. W., Martin, E. L., Krueger, G. M., & Rojas, V. A. (1989). Eye movement in air-to-air combat tasks. In AIAA Flight Simulation Technologies Conference and Exhibit, A Collection of Technical Papers (AIAA Paper No. 89-3323, pp. 422-425). Washington, DC: American Institute of Aeronautics and Astronautics.

Dixon, K. W., Martin, E. L., Rojas, V. A., & Hubbard, D. C. (1988). The effects of field-of-view on pilot performance in the C-130 WST. In Proceedings of the 10th Interservice/Industry Training Systems Conference (pp. 362-371). Arlington, VA: National Security Industrial Association.

Dixon, K. W., Martin, E. L., Rojas, V. A., & Hubbard, D. C. (1990). Field-of-view assessment of low-level flight and an airdrop in the C-130 Weapon System Trainer (WST) (AFHRL-TR-89-9, AD-A218 504). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Dixon, K. W., Rojas, V. A., Krueger, G. M., & Simcik, L. (1990). Eye tracking device for the measurement of flight performance in simulators (AFHRL-TP-89-18, AD-A220 075). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Evans, R. J., & Gainer, J. C. (1989). Safety evaluation of infrared lamp power output for oculometer eye/head tracker system (AFHRL-TP-89-63, AD-A215 809). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Nadel, J. I., & Warner, H. D. (1988). A human factors evaluation of the Visual System Component Development Program (VSCDP) eye-tracking system. In Proceedings of the IEEE 1988 National Aerospace and Electronics Conference, NAECON 1988 (Vol. 3, pp. 915-917). New York, NY: Institute of Electrical and Electronics Engineers.

Pierce, B. J., Felber, A. A., & Wetzel, P. A. (1993). Real image display effects on oculomotor response and the perception of spatial relationships. In J. Morreale (Ed.), 1993 SID International Symposium Digest of Technical Papers, Volume XXIV (pp. 502-505). Playa del Rey, CA: Society for Information Display.

Robinson, R. M., Thomas, M. L., & Wetzel, P. A. (1989). Eye tracker development on the Fiber Optic Helmet Mounted Display. In J. T. Carollo (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1116, Helmet-Mounted Displays (pp. 102-108). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Wetzel, P. A. (1991). Development and evaluation of an eye measurement system for flight simulation. In Visual Issues in Training and Simulation Presentation Summaries (pp. 83-89). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory. (No abstract)

Wetzel, P. A., Thomas, M. L., & Williams, T. T. (1990). Development and evaluation of eye tracker performance for use with the Fiber Optic Helmet Mounted Display. In Proceedings of the 12th Interservice/Industry Training Systems Conference (pp. 273-280). Arlington, VA: National Security Industrial Association.

27. HEAD-MOVEMENT CHARACTERISTICS

Dixon, K. W., Krueger, G. M., Rojas, V. A., & Martin, E. L. (1990). Visual behavior in the F-15 Simulator for Air-to-Air Combat (AFHRL-TP-89-75, AD-A218 648). Williams AFB, AZ: Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Dixon, K. W., Martin, E. L., & Krueger, G. M. (1989). The effect of stationary and head-driven field-of-view sizes on pop-up weapons delivery. In Proceedings of the 11th Interservice/Industry Training Systems Conference (pp. 137-141). Arlington, VA: American Defense Preparedness Association.

Dixon, K. W., Martin, E. L., & Krueger, G. M. (1990). Effects of field-of-view sizes on pop-up weapons delivery (AFHRL-TR-89-51, AD-A223 018). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Duff, J. M. (1983). Real visual image compensation for head motion parallax effects as a function of object distance (AFHRL-TP-83-37, AD-A132 915). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Warner, H. D., Serfoss, G. L., & Hubbard, D. C. (1993). Effects of area-of-interest display characteristics on visual search performance and head movements in simulated low-level flight (AL-TR-1993-0023, AD-A264 661). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

28. OPTICAL FLOW

Owen, D. H. (1984). Optical flow and texture variables useful in detecting decelerating and accelerating self-motion (AFHRL-TP-84-4, AD-A148 718). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Owen, D. H. (1985). Optical and event-duration variables affecting self-motion perception (AFHRL-TP-85-23, AD-A161 836). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Owen, D. H., Freeman, S. J., Zaff, B. F., & Wolpert, L. (1987). Perception and control of simulated self motion (AFHRL-TR-87-16, AD A187 444). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Owen, D.H., Wolpert, L., Hettinger, L.J., & Warren, R. (1984). Global optical metrics for self-motion perception. In E.G. Monroe (Ed.), Proceedings of the 1984 IMAGE II Conference (AFHRL-TR-84-36, AD-A148 636, pp. 405-415). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory. (No abstract)

29. HUMAN VISION CHARACTERISTICS

Kruk, R., Regan, D., Beverley, K. I., & Longridge, T. (1981). Correlations between visual test results and flying performance on the Advanced Simulator for Pilot Training (ASPT). Aviation, Space, and Environmental Medicine, 52(8), 455-460.

Kruk, R., Regan, D. M., Beverley, K. I., & Longridge, T. M. (1982). Visual channel sensitivity and pilot performance in a flight simulator. In R. E. Edwards & P. Tolin (Eds.), Proceedings of the Human Factors Society 26th Annual Meeting (pp. 885-889). Santa Monica, CA: Human Factors Society.

Kruk, R., Regan, D., Beverley, K. I., & Longridge, T. (1983). Flying performance on the Advanced Simulator for Pilot Training and laboratory tests of vision. Human Factors, 25(4), 457-466.

Regan, D. M., Kruk, R., Beverley, K. I., & Longridge, T. M. (1981). The relevance of channel theory for the design of simulator imagery. In E. G. Monroe (Ed.), Proceedings of the 1981 IMAGE II Conference (AFHRL-TR-81-48, AD-A110 226, pp. 307-344). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Regan, D., Kruk, R., Beverley, K., & Longridge, T. (1981). A visual channel theory approach to pilot performance and simulator imagery. In R. C. Sugarman, A. S. Baum, J. L. Ditzian, D. J. Funke, V. J. Gawron, & K. R. Laughery (Eds.), Proceedings of the Human Factors Society 25th Annual Meeting (pp. 223-227). Santa Monica, CA: Human Factors Society.

30. VISUAL TARGET ACQUISITION

Kerchner, R. M., Hughes, R. G., & Lee, A. (1983). TAC BRAWLER: An application of engagement simulation modeling to simulator visual system display requirements for air combat maneuvering. In R. S. Jensen (Ed.), Proceedings of the Second Symposium on Aviation Psychology (pp. 599-606). Columbus, OH: Ohio State University.

31. IMAGE QUALITY MEASUREMENT

Chi, C. & Pollak, E. (1984). Control systems analysis program: A tool for analysis of the GE-VSCDP image display system. In E.G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 267-278). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory. (No abstract)

Evans, R. J. (1990). Image quality metrics and application of the Square Root Integral (SQRI) metric: An overview (AFHRL-TR-90-56, AD-A229 753). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Evans, R. (1990). Image quality metrics and performance of visual display systems. In E. G. Monroe (Ed.), Proceedings of the 1990 IMAGE V Conference (pp. 274-282). Tempe, AZ: IMAGE Society, Inc.

Evans, R. J. (1991). Display image quality: Scaling of contrast, brightness, and resolution. In Visual Issues in Training and Simulation Presentation Summaries (pp. 75-79). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory. (No abstract)

Evans, R. J. (1993). Image quality and the display modulation transfer function: Experimental findings (AL/HR-TR-1993-0131, AD-A274 061). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Evans, R. J. (1994). Empirical approach to visual display preference based upon modulation transfer function and luminance (AL/HR-TR-1994-0107, AD-A285 450). Mesa, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Kelly, G. R. (1992). Measurement of modulation transfer functions of simulator displays (AL-TP-1992-0056, AD-A259 401). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

32. SIMULATOR SICKNESS

Warner, H. D., Serfoss, G. L., & Baruch, T. M. (1991). Flight simulator side effects and visual displays evaluation. In Visual Issues in Training and Simulation Presentation Summaries (pp. 20-24). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory. (No abstract)

Warner, H. D., Serfoss, G. L., Baruch, T. M., & Hubbard, D. C. (1992). Flight simulator-induced sickness and visual systems evaluation. In A. J. Aretz (Ed.), Proceedings of the Thirteenth Symposium Psychology in the Department of Defense (USAFA TR 92-2, pp. 11-15). Colorado Springs, CO: Department of Behavioral Sciences and Leadership, U.S. Air Force Academy.

Warner, H. D., Serfoss, G. L., Baruch, T. M., & Hubbard, D. C. (1993). Flight simulator-induced sickness and visual displays evaluation (AL/HR-TR-1993-0056, AD-A267 019). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

33. SIMULATION EVALUATION

Crane, P. M. (1993). Evaluation of two wide field-of-view display systems for air combat training. In Proceedings of the 13th International Display Research Conference, Euro Display '93 (pp. 171-174). Brive, France: Le Club Visu.

Crane, P. M. (1994). Evaluation of two wide-field-of-view display systems for air combat training. Journal of the Society for Information Display, 2(1), 59-61.

Reid, G. B., & Cyrus, M. L. (1977). Formation Flight Trainer evaluation for T-37 UPT (AFHRL-TR-77-23, AD-A043 197). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Waag, W. L. (1981). Training effectiveness of visual and motion simulation (AFHRL-TR-79-72, AD-A094 530). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

34. RESEARCH REQUIREMENTS

Richards, W., & Dismukes, K. (1982). Vision research for flight simulation (AFHRL-TR-82-6, AD-A118 721). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

35. IMAGE CONFERENCE PROCEEDINGS

Monroe, E. G. (Ed.). (1977). Proceedings of the 1977 IMAGE Conference (AD-A044 582). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Monroe, E. G. (Ed.). (1981). Proceedings of the 1981 IMAGE II Conference (AFHRL-TR-81-48, AD-A110 226). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Monroe, E. G. (Ed.). (1984). Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

SECTION II. REFERENCES AND ABSTRACTS

Bell, H.H., & Cuiffreda, K.J. (1985). Effects of collimation on accommodation and vergence in the Advanced Simulator for Pilot Training (AFHRL-TP-85-27, AD-A159 545). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Accommodation and binocular vergence were measured using a haploscope optometer for 10 observers who viewed collimated (i.e., 0.15 diopter) and noncollimated presentations of a simulated approach and landing. Collimated imagery produced a small but consistent decrease in accommodation for each observer. Collimation also produced an increase in the perceived size of objects within the visual scene. These results suggest that the primary influence of collimation is on binocular vergence and that differences in the perceived quality of collimated and noncollimated simulator displays are due to differences in binocular vergence rather than in accommodation.

Booth, G. R. (1988). Visual simulation for advanced fighter training. In Proceedings of the 10th Interservice/Industry Training Systems Conference (pp. 108-114). Arlington, VA: National Security Industrial Association.

This paper examines the background of fighter aircraft visual simulation, training requirements in support of realistic combat scenarios, present visual simulation capabilities, and, for the future, advanced visual tactical training centers. Advances in Soviet weapons technology is increasing the threat to aircrew survival and mission success, thereby emphasizing the importance to train aircrews in a realistic combat environment. Unfortunately, combat-related skills cannot be fully trained in the aircraft due to limits of the training environment. These limitations include airspace, weather, safety, ordnance, and cost. The increased threat and limited peacetime training operations combine to place new and increasingly complex demands on today's tactical simulators. Currently, limited visual training capability exists for fighter aircraft simulators. However, today's technology is rapidly advancing to a state that future combat flight simulators will be equipped with visual, sensor, electrooptical, and radar databases, photographic in quality, that accurately replicate any location in the world. These simulators will be capable of providing mission scenarios that include all known threats, synergistic effects of electronic combat, and command and control. They will be located at tactical training centers and will train combat skills to tactical aircrews realistically and effectively.

Buckland, G. H. (1980). Flight simulator runway visual textural cues for landing. In G. E. Corrick, E. C. Haseltine, & R. T. Durst, Jr. (Eds.), Proceedings of the Human Factors Society 24th Annual Meeting (pp. 286-287). Santa Monica, CA: Human Factors Society.

The effect of visual textural patterns superimposed upon the runway touchdown zone area was studied as a potential factor in excessive vertical velocity at touchdown during flight simulation. Six simulated daytime runways with varying degrees of textural cues, as well as one night runway scene, were used. The average vertical velocities at touchdown were higher in the simulator than comparable test landings in actual aircraft, but the textural cues did produce statistically significant

differences in simulated vertical velocities at touchdown. Apparently the texture patterns did help to improve pilot performance, but they were not sufficient by themselves to completely solve the problem of excessive vertical velocities at touchdown.

Buckland, G. H. (1980). Visual cue requirements for terrain flight simulation. In Proceedings of the 2nd Interservice/Industry Training Equipment Conference and Exhibition (pp. 92-93). Arlington, VA: National Security Industrial Association.

Three types of visual scene cues were varied in order to determine their effect on pilot performance during simulated low-altitude flight. The three types of visual cues consisted of three sizes of ground texture patterns, the presence or absence of vertical object cues, and the presence or absence of an aircraft shadow. The pilots who flew the simulated missions reported that all three visual cues were useful, however, the vertical object cues and texture patterns were more useful than the aircraft shadow. Both the texture patterns and the vertical object cues produced statistically significant differences in quantitative measures of pilot performance.

Buckland, G. H., Edwards, B. J., & Stephens, C. W. (1981). Flight simulator visual and instructional features for terrain flight simulation. In E. G. Monroe (Ed.), Proceedings of the 1981 IMAGE II Conference (AFHRL-TR-81-48, AD-A110 226, pp. 350-362). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Lack of adequate visual scene detail is a serious limitation in the use of CGI for training low-altitude terrain flight. Terrain flight profiles involve both low-level contour flight that closely follow the profile of the ground and nap-of-the-earth flight, which includes maneuvering between and around vertical obstructions. Both ground textural pattern cues and vertical object cues appear to be important for pilots to judge aircraft height above the ground. AFHRL/OT has conducted research on both of these types of visual cues and is currently developing an optimal ASPT visual environment for instructing terrain flight maneuvers. These efforts are addressed in this paper.

Buckland, G. H., Monroe, E. G., & Mehrer, K. I. (1977). Simulator runway touchdown zone visual requirements; textural visual cue considerations. In E. G. Monroe (Ed.), Proceedings of the 1977 IMAGE Conference (AD-A044 582, pp. 174-184). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Many different flight maneuvers have been studied using flight simulators with visual systems, but one that has not received much attention is the flare and final touchdown. One criticism suggested is the lack of adequate textural information in the visual scene, which is needed to provide good cues for depth perception. With the flexibility and rapid variation of the visual scene content of a CIG system, a detailed investigation of these visual cues is both possible and practical. The ASPT has such a CIG system with the capability to support this type of research. This paper

summarizes the engineering modifications to the CIG and basic ASPT systems and the data collection for the first study of runway textural visual cues.

Buckland, G. H., Monroe, E. G., & Mehrer, K. I. (1980). Flight simulator runway visual textural cues for landing (AFHRL-TR-79-81, AD-A089 434). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The effects of seven different runway types were investigated on pilot performance during landings in a T-37 flight simulator. Data were also gathered on six of the same 12 pilots during actual T-37 aircraft landings at the Air Force Flight Test Center, Edwards AFB, CA. The seven simulated runways consisted of one night runway and six day runways with varying amounts of textural information cues on the runway touchdown zone area. The night runway was also tested with and without touchdown zone landing lights (TD-Zone lights), and the day runways were tested with and without the runway overruns. The simulated aircraft average vertical velocity at touchdown decreased systematically from 201 ft/min for the night runway without the TD-Zone lights to 136 ft/min for the day runway with 4-ft texture patterns. The day runways alone, without the overrun, varied from 195 ft/min for the Bare Bones runway to 136 ft/min for the 4-ft texture pattern. Although these average vertical velocities were still much higher than those recorded in the actual aircraft (32 ft/min), the texture patterns did influence the pilot flare and touchdown in a systematic manner. The presence of the TD-Zone lights in the night scene also reduced the average vertical velocity at touchdown (190 ft/min), but this difference was not statistically significant. The presence of the runway overruns on the daytime runways limited the overall range of touchdown vertical velocities to a smaller range spanning from 176 ft/min for the "Willie" runway to 158 ft/min for the 4-ft textured runway. When the overrun was present, apparently the pilots used the overrun visual cues, the chevron texture patterns, and other related cues, in addition to the runway texture patterns, in order to perform the flare and touchdown. This resulted in reduced overall touchdown vertical velocities, but apparently the more uniform pilot performance (restricted range) did not involve an optimum use of the 4-ft texture patterns. Several other data parameters also varied across runway types; however, there were no consistent differences related to runway texture patterns. The significant effects with the other data parameters were most often related to differences between the night and the day runway scenes.

Bunker, R. B., & Fisher, R. (1984). Considerations in an optical variable acuity display system. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 239-251). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This paper describes an effort to establish feasibility and quantify parameters of a truly optimal simulator visual system, i.e., one that fully satisfies human visual requirements with an absolute minimum of processing and display equipment. The concept is described and compared to alternate approaches with respect to size and complexity. The current effort to define parameters required to minimize potential operator distractions is described and results to date are presented.

CAE Electronics Ltd. (1983). Wide-field-of-view, helmet-mounted infinity display system development (AFHRL-TR-84-27, AD-A149 641). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This report details the development of a fiber-optic-coupled helmet-mounted display. A working breadboard model has been developed. A computer-generated image projected from a light valve is relayed to the input of a large-format, coherent fiber-optic bundle. The fiber-optic bundle transfers the image to a set of helmet-mounted optics that display the imagery via two in-line, wide-angle infinity displays. Helmet position and attitude are sensed and used to control the image content. Research was also conducted on the requirement for eye-slaved control of image content.

Carey, M. S., Densmore, J. E., Jr., Kerchner, R. M., Lee, A. T., & Hughes, R. (1983). Effects of transport delay on simulator air-to-air engagements (AFHRL-TR-83-8, AD-A133 707). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The TAC BRAWLER engagement simulation model for air-to-air combat was used to investigate the effects of visual system transport delays associated with hypothetical head-slaved, helmet-mounted display systems. Transport delays of 0, 52, 100, and 173 ms were studied with respect to their effects upon both the performance outcomes of one-versus-one and two-versus-two air combat scenarios. In general, degradation of pilot tracking performance (as defined in terms of the components of TAC BRAWLER's tracking model) was found to be an increasing function of transport delay duration with the most significant effects being on line-of-sight error and transverse velocity error. Neither advantage time nor duration of advantage time measures were found to be sensitive to transport delay. While additional model validation is required for predicting the precise effects of transport delay on training effectiveness, the data do serve to demonstrate the sensitivity of pilot tracking performance and mission outcome to transport delay.

Collyer, S. C., Ricard, G. L., Anderson, M., Westra, D. P., & Perry, R. A. (1980). Field of view requirements for carrier landing training (NAVTRAEQUIPCEN-IH-319/AFHRL-TR-80-10, AD-A088 701). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory; Orlando, FL: Naval Training Equipment Center.

A study was conducted to investigate simulator visual FOV requirements in conjunction with two approaches to training daytime carrier circling approach and landing. The study found that evidence does not support a requirement for a wide-angle visual display for the training of circling approaches and carrier landings. Three groups of U.S. Air Force T-38 IPs were given simulator training in aircraft carrier landings. These pilots were taught execute a landing on a simulated aircraft carrier in the ASPT. The visual image for the simulation was provided by a database that created the aircraft carrier USS Forrestal (CVA-59) in the ASPT CIG system. The pilots in these three groups were trained under different conditions. Two groups flew a circling approach with

one group using a wide (i.e., 300-deg horizontal by 150-deg vertical) visual FOV and the other group using a narrow FOV (i.e., 48-deg horizontal by 36-deg vertical). A third group flew a straight-in approach using the narrow FOV. A variety of performance measures were taken to characterize the carrier approach. These measures were categorized as (a) instantaneous measures, (b) continuous measures, (c) measures representing the success of the approach at touchdown, and (d) Landing Signal Officer ratings. Various statistical routines were carried out with the results obtained from these measures. Results indicate that, for carrier circling approaches and landings, there are no clear training advantages of a wide-angle visual display. Practice on straight-in approaches using a narrow-angle visual display appears to be the most cost-effective use of simulators for training this task.

Cook, P. A. (1982). Aerial combat simulation in the U.S. Air Force. In <u>Proceedings of the AIAA Computer Graphics Symposium, Phoenix Section</u> (AIAA Paper No. 82-3003, pp. 16-19). New York, NY: American Institute of Aeronautics and Astronautics.

The history, current applications, research programs, and features of future air combat simulators for pilot training are reviewed. The Link system, invented in 1929, provided good cockpit orientation and instrumentation instruction. Current U.S. Air Force simulators, specifically those located in Phoenix, AZ, are mounted on six-DOF motion simulators. Seven visual display screens provide a 300-deg horizontal by 140-deg vertical FOV and are configured for A-10 and F-16 fighters. Experiments with pilots trained in simulators and in classrooms for strafing and air-to-ground bombing missions have demonstrated that simulator trained pilots are more proficient in real flights past the seventh mission. Improvements in full combat simulation are reviewed, noting that human eyes are still keener than raster scans, and techniques for improving resolution and developing multiple interactive cockpits are outlined.

Coward, R. E., & Rupp, A. M. (1982). <u>Simulator for Air-to-Air Combat versus real world: Visual cue analysis for simulated air-to-air combat training</u> (AFHRL-TR-81-26, AD-A110 570). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Flying an aircraft requires a continuous interpretation of the visual environment in which the pilot uses visual information from outside the cockpit and from the flight instruments inside the cockpit to develop and maintain an awareness of the status of the aircraft and its location in space. Flying a high-speed, high-performance aircraft in an air-to-air combat environment vastly increases the complexity of the pilot's task. The pilot must also keep track of and evaluate the performance of any opposing aircraft. To maintain a dynamic awareness of the situation and ultimately to be successful in the airborne arena, the pilot depends heavily on interpretation of out-of-the-cockpit visual cues. Usually training of the necessary visual skills for air-to-air combat takes place entirely in the aircraft, a high stress environment where the student pilot quickly can become overwhelmed with visual information. In addition, the training is severely limited by both rules of engagement and aircraft safety limitations that prevent the student pilot from experiencing and practicing

maximum performance tactics. Often the result is inadequate air combat skills, so that additional training is required once the pilot is assigned to an operational squadron. New technology that provides visual display systems for flight simulators now makes it possible for many flying tasks to be more safely and more effectively trained than in the past. However, many simulator training programs have suffered from the erroneous assumption that transfer of training to the aircraft depends on the degree of realism provided by the simulator. The purpose of this research effort was to determine the out-of-the-cockpit visual cues that are essential for air-to-air combat training, and to evaluate the adequacy of visual cues provided by the SAAC.

Crane, P. M. (1993). Evaluation of two wide field-of-view display systems for air combat training. In Proceedings of the 13th International Display Research Conference, Euro Display '93 (pp. 171-174). Brive, France: Le Club Visu.

A simulator system for training air combat skills was evaluated by having teams of experienced pilots fly simulated missions. The simulators used were equipped with two different types of wide-FOV visual display systems. Pilot evaluations demonstrated that wide-FOV displays are necessary for multiship simulator training, even for tasks considered to be nonvisual.

Crane, P. M. (1994). Evaluation of two wide-field-of-view display systems for air combat training. Journal of the Society for Information Display, 2(1), 59-61.

A simulator system for training air combat skills was evaluated by having teams of experienced pilots fly simulated missions. The simulators used were equipped with two different types of wide-FOV visual display systems. Pilot evaluations demonstrated that wide-FOV displays are necessary for multiship simulator training, even for tasks considered to be nonvisual.

Crane, P. M., Gerlicher, J. P., & Bell, H. H. (1986). Flight simulator: Comparison of resolution thresholds for two light valve video projectors (AFHRL-TP-85-43, AD-A164 577). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This project was conducted to measure resolution thresholds, from several observers, for the General Electric PJ5155 and SODERN SVS-14 light-valve video projectors. Thresholds for stationary targets were measured using a stairstep-constant stimulus procedure at two luminances and five screen positions; data were collected from three observers. Results showed that thresholds were lower for the General Electric projector at 60 fL, while the thresholds were equal at 100 fL. Thresholds for moving targets were measured using a two-stage, double stairstep procedure. Data were collected from three observers for targets moving horizontally, vertically, and diagonally at 3.75, 7.5, and 15 deg/s. For all conditions, the General Electric projector had lower thresholds than did the SODERN. With horizontally moving targets, however, the General Electric projector's thresholds were elevated compared to thresholds for vertically or diagonally moving

targets. This threshold elevation is thought to be due to a pattern of vertical bars which is visible only when tracking a horizontally moving target.

Cyrus, M. L. (1977). Method for compensating transport lags in computer image generation visual displays for flight simulation (AFHRL-TR-77-6, AD-A040 551). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

This paper examines an analytical technique for simultaneously compensating transport delays in CIG visual systems while eliminating high frequency "flutter" effects.

Cyrus, M. L., & Fogarty, L. (1978). Advanced simulation for new aircraft. In Proceedings of the 11th NTEC/Industry Conference (NAVTRAEQUIPCEN IH-306, pp. 103-108). Orlando, FL: Naval Training Equipment Center.

The traditional procurement process for new military aircraft simulators results in a long, costly, and dangerous delay in availability of training equipment, after introduction of the aircraft. The ASPT has been modified to provide early simulation of the A-10 and F-16 aircraft. The resulting advance in A-10 program development has been dramatic. Although not yet fully operational, the ASPT F-16 simulation will provide at least comparable benefits for F-16 training program development. The ASPT modification program demonstrates a reasonable method of greatly improving availability and effectiveness of simulator training programs.

Daum, K. M. (1991). The eye movement behavior of pilots. In Visual Issues in Training and Simulation Presentation Summaries (pp. 90-94). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

This study was designed to determine whether the conjugate eye-movement tracking of carrier-based fighter pilots is different from that of controls. We hypothesized that, compared to a seamen control group, pilots flying high-performance aircraft have superior ocular-tracking capabilities because of the highly visual demands of the flying task. We used an IR limbus tracker to measure the eye movements of 65 subjects in the U.S. Navy (i.e., ages 18 to 45 years; 31 pilots, 29 controls, and 5 helicopter pilots). All subjects tracked 19 trials of a small (i.e., 0.4 deg) line on a CRT (i.e., max. amplitude = 17 deg). All subjects tracked the following waveforms: two square waves (i.e., 0.25 and 1.0 Hz); two types of random square waves (i.e., multiamplitude and ternary); four sine waves (i.e., 0.1 to 1.0 Hz); a random, smooth waveform; and five repetitions of a cubic waveform (i.e., 1 Hz). The mean deviations ([MD] i.e., the mean absolute value of the eye position versus the stimulus) for the cubic waveforms were all significantly smaller for the pilots compared to the controls (p = 0.048 to 0.002). For example, MDs trial 1: 2.2 deg, standard deviation = 0.4 deg, versus 2.70 deg, standard deviation = 0.7 deg. Although the MDs of the eye from the stimulus were generally in the hypothesized direction for the other waveforms, none reached statistical significance. We conclude that there is evidence suggesting that there are

differences in the ocular-tracking capabilities of these two groups of subjects. These differences may prove useful in the selection, evaluation, and/or training of individuals performing complex tasks where vision is a major component.

De Maio, J., Bell, H. H., & Brunderman, J. (1985). Pilot-oriented performance measurement (AFHRL-TP-85-18, AD-A158 849). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Aircrew performance measurement is a critical problem in evaluating the quality of a visual simulation system and in determining the effectiveness of aircrew training devices. An effective performance measurement system must be able to separate performance into appropriate components and describe the relationship of these components. This paper describes a performance measurement system developed to analyze pilot performance in maintaining altitude in both straight and turning flight as a function of the object density of the simulated visual environment. The analysis indicates that pilot performance can be divided into perceptual and task difficulty factors and that the effect of the visual environment on each of these factors can be determined. A prototype performance measurement system was developed to describe pilot performance in a simulator. The pilot's task was to maintain altitude at 200 ft both in straight and in turning flight. Pilot performance was sensitive to task difficulty and to visual scene quality. The strength of this performance measurement system was that it analyzed performance in terms of overall task performance and also specific pilot control inputs.

De Maio, J., & Brooks, R. (1982). Assessment of simulator visual cueing effectiveness by psychophysical techniques. In Proceedings of the 4th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 379-381). Arlington, VA: National Security Industrial Association.

Growing emphasis on simulation of low-altitude and air-to-air tactical scenarios has greatly increased the requirement for simulator visual systems capable of providing the pilot high-fidelity out-of-the-cockpit cues. Evaluation of visual system performance through simulator flying studies has been the primary measure of system quality. However, such studies can be costly and time-consuming, and often they provide equivocal results. The present study investigated the use of psychophysical measurement methodology to provide a quick, low-cost evaluation of the altitude cues provided by five visual system displays. Thirty U.S. Air Force pilots made estimates of the altitude above ground level shown in slides of visual system displays varying in object density and object detail. Slides showed a 90-deg FOV scene taken in the F-16 cockpit of the ASPT. Eight altitudes within a range of 50 to 400 ft were presented for each visual scene condition. A random sequence of 40 slides (i.e., 8 altitudes by 5 scenes) was presented three times. Power functions relating perceived to actual altitude were determined. Reliable differences were found between the displays that accorded well with differences found in a simulator flying study using the same display environments. Results are discussed in terms of display features and the measurement methodology.

De Maio, J., & Brooks, R. (1985). Perception of altitude in the low and medium altitude ranges. In R. S. Jensen & J. Adrion (Eds.), Proceedings of the Third Symposium on Aviation Psychology (pp. 505-512). Columbus, OH: Ohio State University.

Research was conducted to determine the effectiveness of CGI in providing visual cues needed for perception of altitude. Questions addressed in the research include: (a) How accurate is perception? (b) How does accuracy of perception vary with altitude? (c) What elements in the CGI scene function as altitude cues? Altitude perception was measured by a magnitude estimation task. Subjects estimated altitude after viewing videotaped presentations of two-dimensional, square texture patterns. Square texture elements varied in size from 450 ft by 450 ft to 4,000 ft by 4,000 ft. Altitudes presented ranged from 50- to 8,000-ft above ground level. Accuracy of perception was indexed by the slope of a regression line of logarithmic-perceived altitude on logarithmic-presented altitude. For sufficiently small texture element sizes, slopes were found to equal asymptotic values reported in the literature. Accuracy of perception was found to be a function of logarithmic altitude. Salient elements in the computer-generated scenes were identified.

De Maio, J., Brooks, R., Brunderman, J., & Rinalducci, E. J. (1983). Visual cueing effectiveness--Comparison of perception and flying performance. In A. T. Pope & L. D. Haugh (Eds.), Proceedings of the Human Factors Society 27th Annual Meeting (Vol. 2, pp. 928-932). Santa Monica, CA: Human Factors Society.

We previously used a free modulus altitude estimation task to evaluate the altitude cuing effectiveness of flight simulator visual environments. The present investigation extends the findings of that work to more detailed visual environments, taking into account a study of the relationship between altitude perception and flying performance. Two experiments with U.S. Air Force pilots and IPs as subjects were conducted. It was found that altitude perceptibility is a valid metric of the ability of a simulator visual display environment to provide a pilot information needed to maintain altitude in low-level flight. A potent cue for altitude perception is provided by the distribution, or flow, of environmental features.

De Maio, J., Rinalducci, E. J., Brooks, R., & Brunderman, J. (1983). Visual cueing effectiveness: Comparison of perception and flying performance. In Proceedings of the 5th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 92-96). Arlington, VA: American Defense Preparedness Association.

Growing emphasis on simulation of low-altitude and air-to-air tactical scenarios has greatly increased the requirement for simulator visual systems capable of providing the pilot high-fidelity, out-of-the-cockpit cues. Evaluation of visual system performance through simulator flying studies has been the primary measure of system quality. Such studies can be costly and time consuming, and often they provide equivocal results. The present set of experiments was conducted to investigate the use of psychophysical measurement methodology to provide quick, low-cost

evaluation of the altitude cuing effectiveness of simulator visual displays. Experiment 1 examined altitude perception in several visual environments. Experiment 2 was a validation effort in which flying performance was evaluated in selected visual environments. In Experiment 1, pilots made altitude estimates based on static and dynamic presentations of visual displays containing texture and varying sizes of three-dimensional objects. Best-fitting power functions were used to relate perceived altitude to actual altitude. In Experiment II, U.S. Air Force pilots flew the ASPT F-16 through five selected visual environments at 600 and 150 ft above ground level. Reliable difference were found as a function of display variables.

deSpautz, J. F., Bender, M. B., & McNamara, V. M. (1980). Flight training simulator: Surface texturing via pseudo random noise codes (AFHRL-TR-80-13, AD-A093 734). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Increased use of IR and low-light-level TV systems within the operational environment has presented increasingly difficult problems to the technology of simulation systems in the area of target identification, textural cues, and simulation fidelity. The principal effort reported here has been to develop a software simulation using cyclic codes for providing surface texture without the use of typical CIG edge-type algorithms. The latter-type algorithms, when used to provide valid and realistic surface detail, cause the edge processing load to exceed system capability. Cyclic-code techniques provide a compact texture database definition that is versatile, has substantial tonal assignment capability, and is based on real-time simulation concepts. The simulator system was delivered and made operational on the Sigma 5 facility using the Advanced CIG Techniques Evaluation System facility for offline video data storage, retrieval, and display. The software is user interactive from a remote terminal and includes capabilities for modeling the database, display characteristics, aircraft positioning, and simulator control of printouts and default options.

Devarajan, V., Hooks, J. T., Jr., & McGuire, D. C. (1984). Low altitude high speed flight simulation using video disc technology. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 53-65). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The LTV Aerospace and Defense Company's visual technology uses video disks as direct access and storage devices of video data obtained from a series of discrete photographs of the gaming area. Each discrete photograph is electronically scanned, converted to video data, formatted, and stored on video disk. When needed for display, the data are retrieved from video disk, processed, and manipulated to display the correct perspective view of the terrain relative to the position and attitude of the simulated aircraft. The pilot has complete freedom of route and attitude within the gaming area. Extensions to the basic video disk technology are currently under development to provide visual simulation of low-level tactical missions. This report describes the algorithm modifications and hardware and software design issues involved in real-time generation of low-level, high-speed scenes. Descriptions are provided of a nonreal-time emulation of concepts and hardware design.

Dixon, K. W., & Curry, D. G. (1987). Effect of scene content and field of view on weapons delivery training. In <u>Proceedings of the 9th Interservice/Industry Training Systems Conference</u> (pp. 247-256). Arlington, VA: American Defense Preparedness Association.

Two of the issues faced by designers of modern high-performance aircraft simulators are: (a) the level of visual scene realism required to adequately train complex tasks within the simulator and (b) the FOV required for such training. The experiment discussed in this paper was designed to study both of these problems as they relate to the training of manual dive bombing in the F-16 aircraft. The experiment was performed in two separate simulators using the same visual IGs and database. The first simulator was a FOHMD system with a full, 360-deg field of regard; the second used Wide Angle Collimated (WAC) windows to provide a more restricted FOV. Subjects with no previous fighter aircraft experience were trained to perform 10-, 20-, and 30-deg dive bomb attacks on either a simulated bombing circle, a low-detail airfield target scene, or a high-detail simulation of the same scene. The transfer/test condition was a second different high-detail airfield scene.

Dixon, K. W., & Curry, D. G. (1990). <u>Weapons delivery training: Effects of scene content and field of view</u> (AFHRL-TP-88-29, AD-A227 968). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Two of the issues faced by designers of modern high-performance aircraft simulators are: (a) the level of visual scene realism required to adequately train complex tasks within the simulator and (b) the FOV required for such training. The experiment described in this paper was designed to study both of these problems as they relate to the training of manual dive bombing in the F-16 aircraft. The experiment was performed in two separate simulators using the same visual IGs and database. The first simulator was a FOHMD system with a full 360-deg field of regard; the second used wide-angle collimated windows to provide a more restricted FOV. Subjects with no previous fighter aircraft experience were trained to perform 10-, 20-, and 30-deg dive bomb attacks on either a simulated bombing range, a low-detail airfield target scene, or a high-detail simulation of the same scene. The transfer/test condition was a different high-detail airfield scene.

Dixon, K. W., Krueger, G. M., & Rojas, V. A. (1988). The use of an eye-tracking device for the measurement of flight performance in simulators. In <u>AIAA Flight Simulation Technologies Conference, A Collection of Technical Papers</u> (AIAA Paper No. 88-4613, pp. 222-225). Washington, DC: American Institute of Aeronautics and Astronautics.

The most popular methods used to assess design and training capabilities of a flight simulator are subjective questionnaires and objective performance measures. These types of methodologies suffer from their inability to provide accurate data concerning attention allocation and behavioral strategy. This added information closes the loop in data collection and would help validate the results of a number of studies that have focused on visual system characteristics. Visual attention

information can be collected with an eye-tracking system. One eye-tracking system is described in this paper, along with its advantages and limitations with respect to determining FOV requirements for visual systems. Other areas discussed include system architecture, initial implementation, and future applications.

Dixon, K. W., Krueger, G. M., Rojas, V. A., & Hubbard, D. C. (1989). The effect of instantaneous field of view size on the acquisition of low level flight and 30-degree manual dive bombing tasks. In J. T. Carollo (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1116, Helmet-Mounted Displays (pp. 110-121). Bellingham, WA: SPIE-The International Society for Optical Engineering.

The effect of various instantaneous FOV sizes on the performance of low-level flight and 30-deg manual dive bomb tasks was investigated with an in-simulator transfer-of-training design. The respective horizontal and vertical dimensions of the FOV sizes used were 127 deg by 67 deg, 140 deg by 80 deg, 160 deg by 80 deg, and 180 deg by 80 deg. Two significant univariate effects were found for the FOV interaction in the trial data. There was one significant univariate effect for mean pitch in the dive bomb testing phase, and the data obtained from questionnaires indicate that subjects felt they used out-of-the-window visual clues 15% to 20% more in the full-FOV test condition. It is recommended that a minimum instantaneous FOV of 160-deg horizontal by 80-deg vertical be used to train pilots for low-level flight and manual dive bombing.

Dixon, K. W., Krueger, G. M., Rojas, V. A., & Martin, E. L. (1990). Visual behavior in the F-15 Simulator for Air-to-Air Combat (AFHRL-TP-89-75, AD-A218 648). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Flight simulators have evolved into complex systems capable of providing training for a number of operational tasks. These systems must make optimal use of the available technology to ensure cost and training effectiveness. Particular emphasis is placed on the requirements for FOV. The current research effort investigated the visual behavior of pilots performing air-to-air maneuvers in an F-15 simulator. The subject's eye position was recorded and window usage analyzed to determine what portion of the FOV the pilots used during the task and to obtain data on how pilots use their visual system during flight. The results infer that significant differences exist between window usage and task performed. In general, offensive set-ups showed a greater usage of the front windows, defensive set-ups displayed more usage of peripheral windows, neutral set-ups required little peripheral information, and the mutual support set-ups displayed a mix of all trends. The data from this effort can now serve as a baseline for more extensive investigations and comparisons between different aircraft, pilots, and experience levels.

Dixon, K. W., Martin, E. L., & Krueger, G. M. (1989). The effect of stationary and head-driven field-of-view sizes on pop-up weapons delivery. In <u>Proceedings of the 11th Interservice/Industry Training Systems Conference</u> (pp. 137-141). Arlington, VA: American Defense Preparedness Association.

It is commonly believed that flight simulators capable of supporting tactical combat tasks should possess full-FOV visual displays with high levels of brightness and resolution. The problem of designing such a visual system is that three factors (i.e., FOV, brightness, and resolution) are not independent. For instance, as FOV is increased, brightness and resolution decrease. An attempt to overcome this dilemma uses head-driven visual displays with limited instantaneous FOV. Head-driven systems overcome the full-FOV problem by providing a full field-of-regard for the head-driven instantaneous FOV. Important considerations for head-driven systems are the horizontal and vertical dimensions of the instantaneous FOV. This research examines the effect of the instantaneous FOV size on pilots' ability to perform pop-up weapons deliveries using both stationary and head-driven visual displays. The respective horizontal and vertical FOV sizes used were 127 deg by 36 deg, 160 deg by 80 deg, 160 deg by 88 deg, and 180 deg by 88 deg. A 300-deg by 150-deg size provided a full-FOV control condition. An A-10 dodecahedron simulator configured with a seven-window, color light-valve display, CGI, and a Polhemus magnetic head tracker provided cockpit and display apparatus. Aircraft performance measures (e.g., altitude and airspeed) and head-position data were the dependent measures. Ten F-5 IPs served as subjects. Results did not confirm the initial hypothesis that performance would be better for head-driven conditions and larger FOVs. This may be due to an increased use of instruments in the smaller FOV conditions to maintain performance levels. This conclusion is difficult to verify because no eye-position data were available. However, it is clear that the smallest condition (i.e., 127-deg horizontal by 36-deg vertical) is inadequate to support training.

Dixon, K. W., Martin, E. L., & Krueger, G. M. (1990). <u>Effects of field-of-view sizes on pop-up weapons delivery</u> (AFHRL-TR-89-51, AD-A223 018). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

It is commonly believed that flight simulators for supporting tactical combat tasks should possess full-FOV visual displays with high levels of brightness and resolution. The problem of designing such a visual system is that three factors (i.e., FOV, brightness, and resolution) are not independent. For instance, as FOV is increased, brightness and resolution decrease. An attempt to overcome this dilemma uses head-driven visual displays with instantaneous limited-FOV sizes. Head-driven systems overcome the full-FOV problem by providing a full field of regard for the head-driven instantaneous FOV. Important considerations for head-driven instantaneous systems are the horizontal and vertical dimensions of the instantaneous FOV. The present research examines the effect of the instantaneous FOV size on pilots' ability to perform pop-up weapons deliveries using both stationary and head-driven visual displays. An A-10 dodecahedron simulator configured with a seven-window, color light-valve display, CGI, and a Polhemus magnetic head tracker provided the cockpit and display apparatus. Aircraft performance measures (e.g., altitude

and airspeed), head-position data, and bomb miss distance were the dependent measures. Ten F-5 IPs served as subjects for the experiment and flew all combinations of FOV sizes and display types from five initial points.

Dixon, K. W., Martin, E. L., Krueger, G. M., & Rojas, V. A. (1989). Eye movement in air-to-air combat tasks. In <u>AIAA Flight Simulation Technologies Conference and Exhibit, A Collection of Technical Papers</u> (AIAA Paper No. 89-3323, pp. 422-425). Washington, DC: American Institute of Aeronautics and Astronautics.

FOV size as it relates to the visual behavior of pilots performing air-to-air maneuvers in an F-15 simulator was studied. The subjects were eye-tracked, and window usage was analyzed to assess what portion of the FOV the pilots used during the task and how pilots used their visual system during flight. The SAAC was found to be ideal due to its large FOV size and high-resolution targets. The results of the eye-position data are depicted graphically.

Dixon, K. W., Martin, E. L., Rojas, V. A., & Hubbard, D. C. (1988). The effects of field-of-view on pilot performance in the C-130 WST. In <u>Proceedings of the 10th Interservice/Industry Training Systems Conference</u> (pp. 362-371). Arlington, VA: National Security Industrial Association.

In order to provide a cost-effective simulator training environment, a number of variables must be optimized to meet training requirements with minimum cost. One such variable is the FOV of the visual display. This research investigated the effect of FOV on pilot performance for low-level flight and an airdrop in the C-130 WST. The experiment was performed using two different FOV configurations. The conditions were a wide FOV that used all six windows to provide a 160-deg horizontal by 35-deg vertical visual field and a limited FOV that used the forward four windows to provide a 102-deg horizontal by 35-deg vertical visual field from the left seat (i.e., pilot's). The tasks chosen by subject-matter experts for the study were thought to be those most likely to require information from the peripheral windows. Automated pilot performance measures and eye-position data were collected throughout the study. Twelve experienced C-130 pilots performed four trials over two different routes under both FOV conditions. The pilot performance data showed no strong or consistent effects due to the FOV manipulation. The eye-position data revealed an increased use of the front window and instruments in the limited-FOV condition and a decreased use of the window to the left of the pilot. This effort shows that the peripheral windows may not be required for experienced pilots, but if present, are used, and if absent, alter visual behavior. Based on the results of the experiment, a preliminary conclusion would be to provide a wide FOV when the training objectives include tasks that use a large amount of peripheral information. Before any final conclusions can be reached regarding FOV requirements, the use of the windows from the copilot's position should be addressed, as well as the value for skill acquisition for less experienced pilots.

Dixon, K. W., Martin, E. L., Rojas, V. A., & Hubbard, D. C. (1990). Field-of-view assessment of low-level flight and an airdrop in the C-130 Weapon System Trainer (WST) (AFHRL-TR-89-9, AD-A218 504). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

In order to provide a cost-effective simulator training environment, a number of variables must be optimized to meet training requirements with minimum cost. One such variable is the FOV of the visual display. The present investigation examined the effect of FOV on pilot performance for low-level flight and an airdrop in the C-130 WST. The study was performed using two different FOV configurations. The full-FOV condition used all six windows to provide a 160-deg horizontal by 35-deg vertical visual field. The limited-FOV condition used only the forward four windows to provide a 102-deg horizontal by 35-deg vertical visual field from the left seat (i.e., pilot's). The tasks chosen by subject-matter experts for the study were thought to be those most likely to require information from the peripheral windows. Automated pilot performance measures and eye-position data were collected throughout the study. Twelve experienced C-130 pilots performed four trials over two different routes under both FOV conditions. The pilot performance data showed no strong or consistent effects due to the FOV manipulation. The eye-position data revealed an increased use of the front window and instruments in the limited-FOV condition and a decreased use of the window to the left of the pilot. Results showed that the peripheral windows may not be required for experienced pilots, but that if the windows are turned on, pilots use a different visual strategy. Based on the results of the study, a preliminary conclusion would be to provide a full FOV when the training objectives include tasks that require a large amount of peripheral information. Before any final conclusions can be reached regarding FOV requirements, however, the use of the windows from the copilot's position should be addressed, as well as the value of the peripheral windows for skill acquisition by less experienced pilots.

Dixon, K. W., Rojas, V. A., Krueger, G. M., & Simcik, L. (1990). Eye tracking device for the measurement of flight performance in simulators (AFHRL-TP-89-18, AD-A220 075). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This paper describes the use of an eye-position monitor as a research tool for evaluating the FOV requirements for simulator visual systems. Traditional evaluation methods rely on the use of pilot opinion and/or objective pilot performance measures. Neither provides a direct index of the pilot's visual behavior under alternative FOV conditions. Without a direct measure, interpretation of data is often problematic. The use of an eye-position monitor provides a useful adjunct to these traditional methods. The present paper describes the system architecture, initial implementation, advantages, and limitations and future applications.

Duff, J. M. (1983). Real visual image compensation for head motion parallax effects as a function of object distance (AFHRL-TP-83-37, AD-A132 915). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Parallax effects due to head movement cause an apparent shift of an object in an image plane. The magnitude of this shift can be determined by a simple geometric formula. Using this relationship, a real-image display could provide parallax compensation similar to that of a virtual-image display.

Edwards, B. J., Pohlman, D. L., Buckland, G. H., & Stephens, C. W. (1981). Training low level terrain flight in a simulator. In Proceedings of the 3rd Interservice/Industry Training Equipment Conference and Exhibition (Vol. 1, pp. 56-61). Arlington, VA: American Defense Preparedness Association.

In this experiment, the use of augmented feedback was investigated as a means of training low-altitude perceptual-motor flying skills in a flight simulator. Sixteen T-38 student pilots enrolled in U.S. Air Force UPT participated as subjects. Eight subjects in an experimental group were trained to fly low level in a simulated A-10 aircraft using special altitude prompts (i.e., lights on the glareshield and auditory tones in the headset) to assist them in discriminating altitude cues provided in the simulated visual environment. Eight subjects in a control group received training identical to that of the experimental group, less prompting. A computerized data record system captured a continuous record of altitude, vertical velocity, number of crashes, and other performance parameters on each of eight training trials and two test runs in which prompts were omitted. All subjects flew a total of 10 runs. The prompted group achieved significantly lower altitude performance on two of four critical task segments compared to the control group during the training trials. However, subjects in the prompted group crashed significantly more times per trial than did subjects in the control group during the training. During the test runs, performance of the two groups for altitude, vertical velocity, and frequency of crashes was not significantly different. The results of the experiment do not appear to warrant continued investigation of this technique for low-level training.

Efron, U., Grinberg, J., Reif, P. G., & Braatz, P. (1981). Silicon liquid crystal light valve for flight simulation applications (AFHRL-TR-81-35, AD-A110 928). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The basic objective of this program has been to develop a silicon photoconductor liquid crystal light valve (Si LCLV) for application in wide-FOV simulators. The Si LCLV is expected to offer several advantages over the cadmium sulfide (CdS) photoconductor LCLV, including higher sensitivity, a significantly better switching ratio, higher resolution, and, most importantly, a fast response time to allow higher 60-Hz operation.

Evans, R. J. (1990). <u>Image quality metrics and application of the Square Root Integral (SQRI) metric: An overview</u> (AFHRL-TR-90-56, AD-A229 753). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The purpose of this report was to present an overview of image quality metrics and evaluate the performance of the modulation transfer function area (MTFA) and the square root integral (SQRI) metrics on displays used at the Air Force Human Resources Laboratory. While the MFTA, as indicated by its name, correlates highly with the display MTFA, the SQRI integrates display luminance, contrast as measured through the MTF, and resolution into a single measure in a different fashion. The scalar results obtained from the metrics act as an image of quality for the display device. Analyses results showed that (a) image quality metrics lack the ability to incorporate the relative importance of display luminance; (b) the J measure from the SQRI metric emphasizes low spatial frequency information (less than 5 cycles/deg) relative to high spatial frequencies; (c) only one of the two measures, the J index, yielded unambiguous results; (d) small variability in the low spatial frequency of the MTFA could cause large changes in the resulting SQRI image quality measures; and (e) the concept of the display modulation depth curve or display MTF employed in image quality metrics is ambiguous and requires some form of further standardization.

Evans, R. (1990). Image quality metrics and performance of visual display systems. In E. G. Monroe (Ed.), <u>Proceedings of the 1990 IMAGE V Conference</u> (pp. 274-282). Tempe, AZ: IMAGE Society, Inc.

As the number of applications for visual display systems continues to grow, the variety of display systems available also increases. For each individual application, a display system will be chosen based upon a combination of economic constraints, task requirements, and engineering considerations. Image quality assessment provides a vehicle for studying task-related requirements of visual display systems. While the two primary modes of experimentally assessing image quality consist of obtaining display rating data or performance data (e.g., target detection and identification) from observers, measures that are more easily obtained and more generalizable are sought. These measures, which may be called metrics, can be computed directly from display system and observer parameters without the need for recurring experimentation. In this paper, the basis and shortcomings inherent in these metrics are discussed, including their reliance on the display MTF and the need to know more about the way in which the human visual system employs contrast modulation across spatial frequency bands.

Evans, R. J. (1993). <u>Image quality and the display modulation transfer function: Experimental findings</u> (AL/HR-TR-1993-0131, AD-A274 061). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Image quality metrics represent an attempt to quantify differences in the quality of the transmission and display of visual information. This report focuses on components in the image transfer process that contribute to image quality as well as tasks through which image quality may

be empirically defined. Components consist of the content of the original image, display device characteristics, and observer characteristics. Special attention within these three components is given to the display MTF, which has traditionally been the major contributor to image quality metrics. Ambiguities exist in the definition and measurement of display MTFs, and these problems are discussed as they pertain to image quality. Additional discussion includes the use of threshold versus suprathreshold tasks as empirical measures of image quality and the use of the contrast sensitivity function (CSF) versus the MTF of the eye in image quality metrics. An argument is presented that questions the use of either the CSF or MTF for suprathreshold tasks. In order to test the use of display MTFs in metrics, a methodology is described for digitally filtering images with the filter representing hypothetical display MTFs. Although this method permits a subset of display MTFs to be compared, further efforts are required to compare MTFs that exhibit a crossover effect in the spatial frequency domain. Finally, empirical observations suggest that other display parameters (e.g., luminance) must be weighted more heavily in image quality metrics.

Evans, R. J. (1994). <u>Empirical approach to visual display preference based upon modulation transfer function and luminance</u> (AL/HR-TR-1994-0107, AD-A285 450). Mesa, AZ: Aircrew Training Research Division, Armstrong Laboratory.

The purpose of the present research effort was to develop a three-dimensional preference space for displays as a function of the display MTF and average display luminance. For any MTF-luminance combination, then, the goal was to generate a point in the third dimension denoting the preference for that pair. A paired-comparison experiment was conducted where, on individual trials, observers viewed side-by-side images varying in MTF (5 levels) and average luminance (4 levels). The 5 x 4 = 20 combinations of MTF and luminance could be thought of as 20 filters. Preferences on individual trials were cumulated into empirical preference probability matrices, which denoted the probability of preferring any one of the 20 filters over any of the 20 filters. A psychological model of preference, the Bradley-Terry-Luce (BTL) Model was then fit to the matrices to estimate a scale value or preference for each of the 20 filters or points in the three-dimensional space. Regression techniques were used to generate a preference surface in the three-dimensional space from which the preference for any display could be predicted. Additional analyses indicated that not only did ratings differ significantly based upon changes in MTF and luminance, but ratings change significantly as a function of using different scenery in the images. Finally, in predictive equations generated from the data, changes in MTF area (measured in percent contrast x cycles per degree of visual angle) tended to have about three times as much effect on preference as did changes in luminance.

Evans, R. J., & Gainer, J. C. (1989). <u>Safety evaluation of infrared lamp power output for oculometer eye/head tracker system</u> (AFHRL-TP-89-63, AD-A215 809). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The U.S. Air Force is concerned about the possible long-term effects of radiation used to illuminate the eye for eye-tracking purposes. Toward this purpose, measurements were taken to

determine the power output of the halogen lamp from the oculometer of the Honeywell (Type YG1784A01) head and eye tracker used at Operations Training Division of the Air Force Human Resources Laboratory. Radiation from the lamp (i.e., General Electric Lamp No. 784, Emergency Lighting-Halogen) is projected through the optics of the helmet onto the user's eye. The returned or reflected signal from the pupillary region of the eye is subsequently analyzed to determine eye position. A thermopile was placed behind a small aperture at the eye position inside the helmet in order to measure the amount of radiation at the eyepoint. Output of the halogen lamp varied with input current where minimum and maximum operational currents were 0.8 and 1 amp. Irradiance measurements recorded using the thermopile were 0.20 mW/cm^2 for an 0.8-amp input and 0.55 mW/cm^2 for a 1-amp input. These readings were determined to be well within safety standards currently set by industry. However, it is suggested that ocular exposure to such radiation be minimized, as more research is required to ascertain chronic effects resulting from long-term exposure of the eye to low levels of radiation.

Farrell, R., & Barker, R. (1983). Integrated cuing requirements (ICR) study: Feasibility analysis and demonstration study (AFHRL-TP-82-25(I), AD-A131 019). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The goal of the Integrated Cuing Requirements (ICR) study was to consolidate and synthesize existing human sensory/perceptual data, principles, and models in a manner that would make this information readily accessible and useful to the community of aircrew training device design engineers. Extensive research literature on human perception exists that could potentially be of value in the specification, design, and evaluation of aircrew training devices. Data in this domain are distributed among numerous different publications and are written in the specialized terminology of perceptual psychology. Consequently, this information is not generally accessible to aircrew training device engineers. The goal of the ICR study was to extract and consolidate the relevant data into an accessible format and to provide, where feasible, a synthesis of the literature that included recommendations relevant to equipment design. The intended output of this activity was (a) an ICR database containing the available sensory/perceptual data in a form useful for specification and design purposes and (b) an ICR users guide to facilitate access to the data by the aircrew training device engineer. Volume I of this technical paper presents the results of an independent feasibility analysis and a subsequent demonstration study evaluation, the purpose of which was to develop, test, and refine an approach to the ICR study objectives discussed above. These activities constituted Phase I of the effort. The project was structured such that no decision on full-scale implementation of the approach (i.e., Phase II) would be made until an evaluation of Phase I had been completed. Volume II of this technical paper contains the Phase I Demonstration Data Base and Users Guide.

Farrell, R., & Barker, R. (1983). Integrated cuing requirements (ICR) study: Demonstration data base and users guide (AFHRL-TP-82-25(II), AD-A131 019). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

(Same abstract as previous reference)

Ferguson, R. L. (1984). AVTS: A high fidelity visual simulator. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 475-486). Williams AFB, AZ: Operations Training Division, Air Force Human Resources

The Advanced Visual Technology System was developed under the auspices of the Air Force Human Resources Laboratory to satisfy the demanding tactical air mission visual system requirements. In particular, the requirement for low-level flight through a high-density, wide-FOV, rolling terrain environment with a large number of moving models on and above the terrain surface posed a formidable system design problem. New developments were required in the critical areas of feature selection, priority, load management, and blending to achieve the requisite scene content. This paper discusses advancements made in these areas and shows that an integrated system design process was essential to the success of the project.

Garrett, J. L., Hepner, J. W., & Howard, C. M. (1993). Color control for flight simulation at Armstrong Laboratory. In R. J. Motta & H. A. Berberian (Eds.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1909, Device-Independent Color Imaging and Imaging Systems Integration (pp. 206-211). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Device-independent color imaging is in use at the Aircrew Training Research Division of the Armstrong Laboratory as a means of individually tailoring colors for each of the display-channel devices used to present visuals for flight simulation. Specifically, an accurate color match across multiple display-channel boundaries is desired. This complex system of color control encompasses the collection of display-channel color characterization data, the processing of that data into individualized red-green-blue color tables, and the utilization of those tables to match the colors of images across display-channel boundaries.

Geltmacher, H. E. (1988). Recent advances in computer image generation simulation. Aviation, Space, and Environmental Medicine, 59(11, Suppl.), A39-A45.

An explosion in flight simulator technology over the past 10 years is revolutionizing US Air Force operational training. The single most important development has been in CIG systems. However, other significant advances are being made in simulator handling qualities, real-time computation systems, and electrooptical displays. These developments hold great promise for achieving high-fidelity combat mission simulation. This article reviews progress to date and predicts its impact along with new computer science advances such as very high speed integraded circuits on future US Air Force aircrew simulator training. Some exciting possibilities are multiship, full-mission simulators at replacement training units, miniaturized unit-level mission rehearsal training simulators, onboard embedded training capability, and national-scale simulator networking.

Geltmacher, H. E., & Seat, J. C. (1983). Wide field-of-view visual display technology for flight simulation. In Proceedings of the IEEE 1983 National Aerospace and Electronics Conference, NAECON 1983 (Vol. 2, pp. 746-753). New York, NY: Institute of Electrical and Electronics Engineers.

Current wide-FOV visual display systems deliver inadequate brightness and resolution necessary for advanced combat simulation. The Air Force Human Resources Laboratory is developing display technologies to solve this problem. These technologies are examined and compared with those incorporated in existing visual display systems. This includes descriptions, advantages, and limitations of solid and liquid crystal light valves, FOHMDs, light collimating techniques, and stereoscopic viewing techniques. A review of human eye requirements and the deficiencies in current systems are presented. Trends on the direction of display technology for simulators are evaluated.

Geltmacher, H., & Thomas, M. (1992). An overview of Air Force combat simulator display development and performance. In J. Morreale (Ed.), 1992 SID International Symposium Digest of Technical Papers, Volume XXIII (pp. 903-905). Playa del Rey, CA: Society for Information Display.

The Armstrong Laboratory has been developing large-FOV display systems for tactical fighter aircraft simulation for over 10 years. An overview is presented that discusses both engineering results and performance evaluations. The successes and failures of six different display developments are discussed.

Geri, G. A., Lyon, D. R., & Zeevi, Y. Y. (1994). Visual evaluation of computer-generated textures (AL/HR-TR-1993-0189, AD-A277 201). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Textures generated by superimposing sinusoidal luminance distributions can be used to simulate the natural terrain textures often used in flight simulator imagery. Because the visual system is spatially inhomogeneous with the periphery being generally less sensitive than the center of the visual field, simpler, more easily generated textures can potentially be used to simulate terrain that is farther from the operator's point of regard. The minimal number of component sinusoids required to generate textures that are visually acceptable in the visual periphery was estimated for the discrimination of complex suprathreshold textures. Specifically, similarity ratings were obtained to determine the effects of component orientation and component phase-bandwidth on the cortical magnification factor (CMF) associated with that discrimination. The textures were designed to be specified by a relatively small number of localized spectral components and sufficiently complex to approximate natural images. The number of component orientations was found to be a particularly important determinant of texture discrimination in that its effect on rated similarity was largely independent of the total number of components making up the texture. When the number of components was varied, a CMF of 2 was sufficient to equate the similarity ratings obtained at 0.75 and 20 deg. Under the same conditions, a CMF of 4 clearly overcorrected the data. The estimated CMF for texture discrimination is much smaller than that found for the discrimination of simple two-dimensional spatial frequency and suggests that either quantitatively different cortical mechanisms or different cortical areas are responsible for the two types of discrimination.

Geri, G. A., & Zeevi, Y. Y. (1985). Visual phenomena produced by binocularly disparate dynamic visual noise (AFHRL-TP-85-4, AD-A154 758). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The use of helmet-mounted displays in flight simulation requires that different visual stimuli be presented to the two eyes. Such disparate stimulation may result in perceptual problems that could adversely affect simulator training. A series of four experiments addressed several perceptual problems associated with the use of binocularly disparate stimuli. The stimulus used in all four experiments was the dynamic visual noise stereophenomenon produced by viewing a detuned TV receiver with the input to one eye attenuated by a light filter. The result is the percept of several counterdirectional dot-planes separated in depth. The purpose of the basic visual research reported here is to further elucidate the visual mechanisms underlying movement aftereffects (Experiment I), binocular rivalry (Experiment II), perceived visual acceleration (Experiment III), and vergence and accommodation to perceived depth (Experiment IV). Each of these phenomena was induced by a form-free texture stimulus perceived as moving inplanes located at various distances from the observer.

Geri, G. A., Zeevi, Y. Y., & Porat, M. (1990). Efficient image generation using localized frequency components matched to human vision (AFHRL-TR-90-25, AD-A224 903). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Following a brief tutorial in the general area of image analysis, a formalism is presented for using the generalized Gabor approach to image representation in the combined frequency-position space. This approach uses elementary functions to which the human visual system is particularly sensitive and that are efficient for the analysis and synthesis of visual imagery. Among the topics covered are the complementarity of position and spatial frequency in the Gabor scheme and the use of an auxiliary function to render the nonorthogonal Gabor elementary functions transformable. The formalism is, in particular, compatible with the implementation of a variable-resolution system wherein image information is nonuniformly distributed across the visual field in accordance with the human visual system's ability to process it. A possible hardware implementation of such a system is described and some potential problems associated with its development are discussed.

Geri, G. A., Zeevi, Y. Y., & Vrana, C. A. (1994). Variable-resolution imagery for flight simulation (AL/HR-TR-1993-0180, AD-A276 199). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

A position-varying, low-pass filter was used to produce variable-resolution images whose spatial frequency content varied as a function of distance from their center. Such images can be matched in some sense to the spatial inhomogeneities of the human visual system, and thus may be visually acceptable even though they contain less information than an unprocessed version of the same image. Following a discussion of image representation with nonuniform sampling and of the concept of locally bandlimited spaces, two experiments were performed to visually assess variable-resolution images. In Experiment 1, images were generated using a series of distortion functions differing in central blur, peripheral blur, and blur gradient chosen to approximate cortical magnification functions (CMFNs) derived from existing anatomical and psychophysical data. The distortion functions, corresponding to the images that were just discriminable from an unprocessed image, were used to define the wide-field CMFN associated with changes in blur discrimination across the visual field. In Experiment 2, blur thresholds were measured using apertures in the form of either circles or 3-deg-wide angular segments centered in either 15-deg or 30-deg eccentricity. Differences in blur discrimination for the two stimulus configurations, matched in area, suggest that the spatial organization of the visual mechanisms underlying blur discrimination changes with eccentricity. Finally, the perceptual data obtained here were used to efficiently sample and represent a variable-resolution image.

Gerlicher, J. P. (1985). Flight simulator: Evaluation of SODERN Visualization System SVS-14 (AFHRL-TP-85-11, AD-A161 794). Williams AFB, AZ: Operation Training Division, Air Force Human Resources Laboratory.

A solid crystal color light-valve display system to be used on flight simulators has been developed by SODERN of France for the General Electric Company under an Air Force Human Resources Laboratory contract. At the completion of the development phase, a prototype projector, designated as SODERN Visualization System SVS-14, was manufactured. The equipment underwent a series of acceptance tests at the SODERN facility and final acceptance testing at the Air Force Human Resources Laboratory. The analysis of the test results showed that the SVS-14 met all important specifications and in some areas even exceeded them. Further experiments with the SVS-14 covered additional engineering evaluations and a human factors study. These tests consisted of a comparison demonstration between the SODERN SVS-14 and the General Electric PJ5155 projector. Ratings of the visual appearance of the imagery produced by the projectors on a side-by-side arrangement of a rear-projection screen were in favor of the General Electric system. However, it was soon found that the performance of the SODERN projector had degraded due to malfunctions of system components. This was caused by a power supply failure that had not been detected prior to the comparison tests. After extensive on-site repair efforts by SODERN personnel, the performance of the SVS-14 was again evaluated in a side-by-side comparison test with the PJ5155. The results indicated improvements in the quality of video imagery. The image persistence for fast-moving objects was about equal for both projectors.

Gertner, I. C., Wolberg, G., Geri, G. A., Kelly, G. R., Pierce, B. J., Thomas, M., & Martin, E. L. (1994). A PC-based photographic-quality image generator for flight simulation. In Proceedings of the 16th Interservice/Industry Training Systems and Education Conference (Paper No. 6-1). Arlington, VA: National Security Industrial Association.

Real-time flight simulation has traditionally required expensive graphics workstations. The goal of this work is to exploit recent advances in processor and memory speeds to design a high-end PC-based multiprocessor IG for flight simulation. By matching computer architecture with the algorithms best suited for this application, a total system can be designed at far less cost than those commercially available. Furthermore, the use of off-the-shelf components will permit the system to benefit from the economies of scale for processor and memory technologies. The principal application targeted here is low-altitude flight over a large terrain. Several key tasks must be addressed for this application: texture mapping, multiresolution terrain and image data, high-quality antialiasing, high-speed geometry pipeline for processing large data sets, and load balancing. This paper describes a low-cost parallel processing solution to these tasks.

Gray, T. H. (1982). Manual reversion flight control system for A-10 aircraft: Pilot performance and simulator cue effects (AFHRL-TR-81-53, AD-A113 463). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The A-10 aircraft incorporates an emergency backup control mode, the Manual Reversion Flight Control System (MRFCS). Maintaining effective control in this mode is a demanding pilot task, but it is not practiced in the flying training syllabus. Because plans call for training this skill using simulation, information was needed on simulator cue requirements. Accordingly, the research objective was to determine the effectiveness of selected simulator visual and force cues used by experienced A-10 pilots to maintain aircraft control and to land when in the MRFCS mode. The experiment found that (a) a large FOV enhanced the pilot's control of the aircraft, (b) platform motion had no influence upon aircraft control, (c) aircraft control was more difficult in the MRFCS mode than in the simple single-engine failure state, (d) point of failure was a significant variable reliably affecting pilot control of the aircraft, and (e) pilot performance improved as a function of practice (i.e., trials).

Hanson, C. L. (1983). Fiber Optic Helmet Mounted Display: A cost effective approach to full visual flight simulation. In Proceedings of the 5th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 262-268). Arlington, VA: American Defense Preparedness Association.

Wide-FOV, high-resolution, detailed visual displays are crucial for the effective simulation of complex air-to-air and air-to-ground combat environments. Current dome and dodecahedron systems are far too costly and lack the combination of required capabilities. The Air Force Human Resources Laboratory is currently developing an FOHMD system that has the potential for filling these demanding requirements. The breadboard FOHMD, built through a Canadian cost-sharing contract with CAE Electronics, displays a head-slaved high-resolution AOI surrounded by a low-resolution background in color. The instantaneous FOV is comparable to the view available to a pilot when wearing a U.S. Air Force helmet. Four image-generation channels and projectors are used to generate individual displays for each eye. The imagery is piped to the helmet via coherent fiber-optic bundles. This system is a valuable research tool for studying many of the issues associated with helmet-mounted displays such as image stability, resolution/brightness/FOV tradeoffs, and visual perception/fatigue.

Hanson, C. L., Longridge, T. M., Barrette, R., Welch, B., & Kruk, R. (1984). Fiber-optic helmet-mounted display for full visual flight simulation. In J. Morreale & J. Hammond (Eds.), 1984 SID International Symposium Digest of Technical Papers, Volume XV (pp. 112-115). Los Angeles, CA: Society for Information Display.

Aircraft simulators have become an integral part of both military and civilian flight training. Technical developments in CIG displays have provided a means to achieve visual simulation. The breadboard FOHMD presents the pilot with a head-slaved instantaneous FOV compatible to that of

a standard helmet. The advantages of higher resolution, higher brightness and lower CIG channel requirements that are available with head-coupled displays can be even further exploited through the use of eye-slaved displays.

Harker, G. S., & Jones, P. D. (1980). Depth perception in visual simulation (AFHRL-TR-80-19, AD-A087 828). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The purpose of the research was to examine human depth perception as it relates to requirements for visual simulation in U.S. Air Force flight simulators. Most, if not all, flying tasks require that depth judgments be made on the basis of extra cockpit visual information. The bases on which such judgments are made by observers in the real world have been the subject of study for more than a century and the majority of the cues have been identified. This effort examines visual displays of a sample of U.S. Air Force and commercial flight simulators in order to assess the efficacy with which these cues are presented in visual simulation systems. A review of the psychophysical and simulation literature was conducted in order to identify the possible cues to depth and their relative importance at various distances and under various conditions. Each of four flying tasks (i.e., approach and landing, formation flying, aerial refueling, and low-level flight) was subjected to a task analysis/cue requirements determination to determine what tasks required depth judgments, whether those judgments were relative or absolute, and to identify the depth cues required for the successful completion of those tasks. Information gained through the task analysis/cue requirements determination was used to subjectively assess visual simulation systems for quality of depth cues presented and to evaluate the need for additional or improved depth cues.

Horowitz, S. J. (1986). Measurements and effects of transport delays in a state-of-the-art F-16C flight simulator. In Proceedings of the 8th Interservice/Industry Training Systems Conference (Vol. 1, pp. 316-321). Arlington, VA: National Security Industrial Association.

In recent years, the military community has developed advanced simulators for high-performance, fighter-type aircraft. These devices not only simulate high-performance aircraft but also complex tasks such as air-to-air combat, aerial refueling, air-to-ground combat, and formation flying. With increases in sophistication of these simulators has come a corresponding increase in computational complexity which has negated the effects of higher computational speeds available in today's computers; thus, transport delays have remained essentially constant. What has not remained constant, however, are effects these transport delays have on training effectiveness of these complex simulators. Because these modern simulators tend to be very complex in nature and consist of many computers interfaced with each other, the determination and measurements of the transport delays is often difficult. The effects these delays have on simulation of a high-performance, fighter-type aircraft are also difficult to determine. The Operations Training Division of the Air Force Human Resources Laboratory is currently completing development of a new F-16C simulator with a full-FOV visual display and no-motion system. This paper describes the methods utilized to measure the transport delays that exist in this system and some of their effects on the training effectiveness of the simulation.

Horowitz, S. J. (1987). Measurement and effects of transport delays in a state-of-the-art F-16C flight simulator (AFHRL-TP-87-11, AD-A187 367). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

In recent years, the military community has developed advanced simulators for high-performance, fighter-type aircraft. These devices simulate not only high-performance aircraft but also complex tasks such as air-to-air combat, aerial refueling, air-to-ground combat, and formation flying. With the increases in the sophistication of these simulators has come a corresponding increase in computational complexity. This complexity has negated the effects of higher computational speeds available in today's computers, thus, the transport delays have remained essentially constant. What has not remained constant, however, are the effects these transport delays have on the training effectiveness of these complex simulators. Because these modern simulators tend to be very complex in nature and consist of many computers interfaced with each other, the determination and measurements of the transport delays are often difficult. The effects these delays have on the simulation of a high-performance, fighter-type aircraft are also difficult to determine. The Air Force Human Resources Laboratory is currently completing the development of a new F-16C simulator with full-FOV visual display and no-motion system. This paper describes the methods used to measure the transport delays that exist in this system and some of their effects on the training effectiveness of the simulation.

Howard, C. M. (1989). Color performance of light-valve projectors. In F. J. Kahn (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1081, Projection Display Technology, Systems, and Applications (pp. 107-114). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Studies completed during the past two years at the Operations Training Division of Air Force Human Resources Laboratory provide comparative data on a single light-valve projector using one xenon arc source and a multiple light-valve projector using two sources and two light valves with common final optics. Spectral energy distributions of light-valve primaries are continuous distributions without the spikes characteristic of some CRT phosphor emissions. Equations relating digital red-green-blue codes to color output must take into account an unavoidable "dark field haze" resulting from the internal optics of these projectors. This haze can be considered as a constant additive factor analogous to ambient illumination on a CRT.

Howard, C. M. (1989). Display characteristics of xample light-valve projectors (AFHRL-TR-88-44, AD-A209 580). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Quantitative data are provided on performance characteristics of light-valve projectors in simulator displays as well as in optimal laboratory conditions. Two types of light-valve projectors are discussed: a single light-valve projector (called Talaria) and a multiple light-valve projector.

The data show that: (a) these projectors do not achieve brightnesses above the mesopic level in large-screen simulator displays, (b) color output includes a dark-field haze that must be dealt with like ambient illumination, and (c) light/dark ratios above 5:1 are obtainable only when the light region is white or yellow-green.

Howard, C. M. (1990). An automated method of device-independent color rendering. In E. G. Monroe (Ed.), Proceedings of the 1990 IMAGE V Conference (pp. 270-273). Tempe, AZ: IMAGE Society, Inc.

This report describes a computer program that automatically collects calibration data on a display device and uses these data, together with an iterative search algorithm, to determine the digital codes required to produce specified colors on that device. The program can be used to match the colors among display areas that receive light from two or more separate projectors.

Howard, C. M. (1990). Measurement of apparent brightness in the mesopic luminance range. In M. H. Brill (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1250, Perceiving, Measuring, and Using Color (pp. 19-25). Bellingham, WA: SPIE-The International Society for Optical Engineering.

In our laboratory, we have undertaken to obtain measurements on the sorts of lights commonly in use for simulator displays driven by real-time IGs. Whether the displays are produced by light-valve projectors or by projection CRTs, these displays have in common that they are limited to the color gamut available from mixtures of three primaries: red, green, and blue. Therefore, I planned to study a typical CRT gamut over a range of five log units from 10 nits to .001 nit as evaluated by photopic instruments.

Howard, C. M. (1994). Color control in a multichannel simulator display: The Display for Advanced Research and Training (AL/HR-TR-1994-0024, AD-A279 717). Mesa, AZ: Aircrew Training Research Division, Armstrong Laboratory.

This report outlines the principles for color matching CGI in displays made up of sectors served by several display devices. These principles are discussed with reference to a particular multichannel simulator display for which the display devices are projection CRTs.

Howard, C. M., & Burnidge, J. (1994). Colors in natural landscapes (AL/HR-TR-1993-0172, AD-A277 204). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

This report supplies chromaticity coordinates and relative luminances of certain natural surfaces for which spectral reflectance distributions are presently available. Modelers of geographical

databases for simulator displays may use this information to guide color selection for scene components. Where the reflectance data permit, relative luminances have also been computed for simulation of landscapes viewed through night vision devices.

Howard, C. M., & Burnidge, J. A. (1994). Colors in natural landscapes. Journal of the Society for Information Display, 2(1), 47-55.

This paper supplies chromaticity coordinates and relative luminances of certain natural surfaces for which spectral reflectance distributions are presently available. Modelers of geographical databases for simulator displays may use this information to guide color selection for scene components. Where reflectance data permit, relative luminances have also been computed for simulation of landscapes viewed through night-vision devices.

Hughes, D. A. (1992). Multiple projector small dome display (AL-TP-1992-0057, AD-A258 621). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

This document describes the Multiple Projector Small Dome Display Project. The goal of this project was to demonstrate the capability of current low-cost LCD projectors to create a low-cost dome display system. Four such projectors were configured to project on a 10-ft-diameter half-dome. The ability of the IG to precorrect the image for the distortion of the curved projection surface was essential because the projectors offered no raster adjustments. As configured for this project, the four projectors provided a FOV of 70-deg horizontal by 45-deg vertical. Performance of the display provided better than 6 arc min/pixel resolution, brightness of 4 fL, and a contrast ratio of 28:1.

Irish, P. A., III, & Buckland, G. H. (1978). Effects of platform motion, visual and G-seat factors upon experienced pilot performance in the flight simulator (AFHRL-TR-78-9, AD-A055 691). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

The objective of this study was to empirically assess the performance of experienced pilots in the ASPT under varying platform motion, G-seat, FOV, and ceiling/visibility conditions. Five experienced T-37 pilots flew five contact and instrument maneuvers in the ASPT under all combinations of the independent variables. Automated performance measures based on system parameters, pilot inputs, and derived scores were collected and analyzed. The results indicated that expert performances were affected by the motion, FOV, and ceiling/visibility variables and were often manifested as changes in control behavior rather than vehicle performance.

Irish, P. A., III, Grunzke, P. M., Gray, T. H., & Waters, B. K. (1977). The effects of system and environmental factors upon experienced pilot performance in the Advanced Simulator for Pilot Training (AFHRL-TR-77-13, AD-A043 195). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

The objectives of the study were: (a) to assess the relative contribution of platform motion, G-seat, and visual factors to pilot performance in the ASPT; (b) to acquire information on the relationships between system output and pilot input measures as collected in the ASPT; and (c) to evaluate the utility of economical multifactor designs for research in flight simulation. Three experienced T-37 pilots flew five maneuvers in the ASPT under combinations of the following independent variables: platform motion, G-seat, FOV, turbulence, wind, and ceiling/visibility. Automated performance measures based on system parameters, pilot inputs, and derived scores were collected and analyzed. Both main and interaction effects of the independent variables were found for a majority of the maneuvers. A discussion of the utility of economical multifactor designs is included. Additionally, implications for determining the direction of future studies are discussed.

Kellogg, R. S., Hubbard, D. C., & Sieverding, M. J. (1989). Field-of-view variations and stripe-texturing effects on assault landing performance in the C-130 Weapon System Trainer (AFHRL-TR-89-3, AD-A212 763). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Two experiments were conducted using the C-130 WST located at Little Rock AFB. These experiments were the first of a series of research and development efforts designed to provide input to specification of the visual requirements for the C-17 flight simulator. Both studies assessed the effect of an experimental manipulation upon pilot performance of an assault landing. The basic experimental design for each was randomized block repeated measures. For each study, 10 experienced C-130 pilots served as subjects. The first study investigated the effect of limiting the FOV of the WST by reducing the five-channel, six-window visual system to two channels and two windows. The second study investigated the effect of database texturing upon pilot performance. No strongly significant FOV effects were obtained in the first study. However, the results of the second study indicated that database texturing improved the pilots' ability to fly at lower altitudes and place the aircraft closer to the centerline during landing and touchdown.

Kellogg, R. S., Kennedy, R. S., & Woodruff, R. R. (1983). Comparison of colour and black-and-white visual displays as indicated by bombing performance in the 2B35 TA-4J flight simulator. Displays Technology and Applications, 4(2), 106-107.

Ten highly qualified and experienced IPs were tested with respect to bombing performance in the General Electric 2B35 full-color wide-screen flight simulator. Half the pilots flew with color first and then black-and-white, the other half with the reverse order. Repeated bombing runs were made and circular bombing errors obtained. Under the conditions of the study, no statistically significant differences were shown between performances in color and those in black-and-white.

Kellogg, R. S., Kennedy, R. S., & Woodruff, R. R. (1984). Comparison of color versus black-and-white visual displays as indicated by bombing and landing performance in the 2B35 TA-4J flight simulator (AFHRL-TR-84-22, AD-A144 674). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Twenty-two highly qualified and experienced U.S. Navy IPs were tested with respect to (a) bombing and (b) landing performance in the General Electric 2B35 TA-4J full-color wide-screen flight simulator. Half the pilots flew with color first and then black-and-white, the other half flew in reverse order. In Phase I of the study, repeated bombing runs were made and circular bombing errors obtained. In Phase II, repeated carrier-type landings were made and critical landing parameters were measured. Under the conditions of the study, no statistically significant differences were shown between performance with color or with black-and-white.

Kellogg, R. S., & Miller, M. (1984). Visual perceptual aspects of low level high speed flight and flight simulation. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 21-35). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The low-level, high-speed flight arena has opened up as a very important one in the past several years. Weapon systems and tactics developments have forced the acquisition of pilot skills in low-level, high-speed flight. In order to remain undetected and complete the mission, the pilot is forced to fly below enemy radar. This carries with it the constant threat of contact with the ground, which is of course as lethal as enemy missiles. As a consequence of this necessity to fly low and fast, a thorough-going training program has been under development for the past three years at the 162nd Fighter Weapons School. The purpose of the present paper is to describe in some detail the visual/perceptual aspects of low-level, high-speed flight as they are currently viewed by the developers of this program. The fighter simulator has already begun to play an important role in this training program, and this role will certainly expand with the fast developing simulator technology in conjunction with better understanding of the training requirements.

Kellogg, R. S., Prather, D. C., & Castore, C. H. (1980). Simulated A-10 combat environment. In G. E. Corrick, E. C. Haseltine, & R. T. Durst, Jr. (Eds.), Proceedings of the Human Factors Society 24th Annual Meeting (pp. 573-577). Santa Monica, CA: Human Factors Society.

The purpose of this study was to test the feasibility of using the ASPT in training pilots for combat in a simulated hostile environment. A combat environment was developed in which a simulated A-10 aircraft was flown. The environment included mountainous terrain and enemy SAMs and AAA. The offensive target was a tank located at random along the roadway. The pilots flew the mission in real time and were scored on offensive and defensive procedures. They showed clear learning for those procedures in the simulator.

Kellogg, R. S., Prather, D. C., & Castore, C. N. (1981). Simulated A-10 combat environment. In E. G. Monroe (Ed.), Proceedings of the 1981 IMAGE II Conference (AFHRL-TR-81-48, AD-A110 226, pp. 35-44). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The purpose of this study was to test the feasibility of using the ASPT in training pilots for combat in a simulated hostile environment. A combat environment was developed in which a simulated A-10 aircraft was flown. The environment included mountainous terrain and enemy SAMs and AAA. The offensive target was a tank located at random along the roadway. The pilots flew the mission in real time and were scored on offensive and defensive procedures. They showed clear learning for those procedures in the simulator.

Kelly, G. R. (1992). Measurement of modulation transfer functions of simulator displays (AL-TP-1992-0056, AD-A259 401). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

The theory and methodology necessary for measuring the MTF of flight simulator displays is presented. The mathematical development of the MTF from linear system theory is outlined. The two primary methods for measuring MTF, namely the direct and indirect methods, are described and compared. The implementation of the indirect method is described in detail including measurement of the line spread function of a display, calculation of MTF from the line spread function, and calibration of the resulting MTF. The MTFs of various simulator display components and displays were measured with the indirect method and presented in graphical form. Some of the more interesting characteristics of each MTF are discussed.

Kelly, G. R., Shenker, M., & Weissman, P. (1992). Helmet-mounted area-of-interest display (AL/HR-TR-1992-0119, AD-A258 275). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

This report describes the results of a design study for a helmet-mounted display for use as an AOI for the Display for Advanced Research and Training (DART). The objective of the research was to investigate alternative optical approaches for building a helmet-mounted AOI for the DART and to recommend the optimal approach based on performance and cost tradeoffs. The experiment examined several system design problems: the design of a helmet-mounted display eyepiece with minimal obtrusiveness, visual blending of the helmet-mounted imagery with the projected imagery, and timing and perspective issues relating to the CGI presented by both the helmet-mounted and the projection display.

Kelly, G., Shenker, M., & Weissman, P. (1992). Helmet-mounted area of interest. In T. M. Lippert (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1695, Helmet-Mounted Displays III (pp. 58-63). Bellingham, WA: SPIE-The International Society for Optical Engineering.

A novel simulator display system is described. The display consists of a full-FOV rear-screen projection display and a narrow-FOV high-resolution helmet-mounted display. The helmet-mounted display is worn by the pilot within the projection display. The virtual image of the helmet-mounted display is thus superimposed upon the real image of the projection display. This hybrid approach to building a wide-FOV display takes advantage of the beneficial aspects of both projection displays and helmet-mounted displays. The result is a low-cost total-FOV display with high resolution. Several system design problems arise in the integration of the helmet-mounted display with the projection display. These issues are discussed and include: the design of an helmet-mounted display eyepiece with minimal obtrusiveness, visual blending of the helmet-mounted display imagery with the projected imagery, and timing and perspective issues relating to the CGI presented by both the helmet-mounted display and the projection display.

Kelly, W. A., & Turnage, G. R. (1977). Area of interest simulation with variable size hood to restrict viewable scene. In E. G. Monroe (Ed.), Proceedings of the 1977 IMAGE Conference (AD-A044 582, pp. 83-105). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

The purpose of this document is to describe the operational characteristics and the functional steps of implementation of the ASPT capability called the AOI/Variable FOV function.

Kerchner, R. M., Hughes, R. G., & Lee, A. T. (1983). TAC BRAWLER: An application of engagement simulation modeling to simulator visual system display requirements for air combat maneuvering. In Proceedings of the International Conference on Simulators (pp. 110-114). London, England: Institution of Electrical Engineers.

The TAC BRAWLER air combat simulation models the acquisition and use of visual information by pilots. It provides designers of manned simulators for air-to-air combat with information regarding training implications of display system resolution, inherent target contrast, FOV, and transport delay. Various display designs can be simulated. The resulting quantitative and qualitative differences in engagements are considered indicators of possible mistraining. Display resolution was found to alter combat primarily through its effect on detection ranges; the pixel averaging contrast management technique largely compensates for this problem. Transport delay significantly degrades pilot tracking ability, but the training impact effect is unclear.

Kerchner, R. M., Hughes, R. G., & Lee, A. (1983). TAC BRAWLER: An application of engagement simulation modeling to simulator visual system display requirements for air combat maneuvering. In R. S. Jensen (Ed.), Proceedings of the Second Symposium on Aviation Psychology (pp. 599-606). Columbus, OH: Ohio State University.

The TAC BRAWLER air combat simulation models both the acquisition and use of visual information by the pilot. It was used to provide the designers of manned simulators for air-to-air combat with information regarding the training implications of display system resolution, inherent target contrast, FOV, and transport delay. Various display designs were simulated, and the resulting quantitative and qualitative differences in engagements were considered indicators of possible mistraining. Display resolution was found to alter combats primarily through its effect on detection ranges. The "pixel averaging" contrast management technique was shown to largely compensate for this problem. Transport delay significantly degrades pilot tracking ability, but the training impact of the effect is unclear.

Kerchner, R., Lee, A., & Hughes, R. G. (1983). Air combat simulation visual display requirements: An application of engagement simulation modeling (AFHRL-TR-82-39, AD-B072 581). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The objective of this study was to evaluate the impact of flight simulator display parameters on the training of aircrews in air-to-air combat. The study utilized a large-scale engagement simulation model, TAC BRAWLER, in the evaluation of a range of display resolution and contrast parameters for displays in which the pilot's FOV is limited only by the aircraft cockpit/airframe. The study also compared the potential training utility of head-slaved, high-resolution displays of limited FOV with an unlimited-FOV display condition. The results of the study indicate that realistic air combat simulation will require a minimum of 2 arc min/line limiting resolution. Contrast management techniques were found to be capable of providing the effects of systems with higher than 2 arc min resolution. Head-slaved, high-resolution inset areas as alternative to unlimited-FOV displays were found to provide inadequate visual information for the pilot in multiple aircraft engagements. An analysis of the results of comparisons between head-slaved systems of varying resolution and FOV revealed that a poorer resolution system with a larger FOV was more desirable than a high-resolution but smaller FOV system.

Kleiss, J. A. (1990). Terrain visual cue analysis for simulating low-level flight: A multidimensional scaling approach (AFHRL-TR-90-20, AD-A223 564). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Multidimensional scaling was used to analyze the features of real-world terrain that are salient to pilots during low-level flight. The stimuli were nine short (5-s) videotape segments depicting low-level, high-speed flight over a variety of terrain types. The segments were paired in all possible combinations, yielding a total of 36 stimulus pairs. Fifteen experienced pilots rated the visual

similarity of each terrain pair on a 10-point scale anchored at 0 with Highly Dissimilar and at 9 with Highly Similar. The rating data were submitted to a nonmetric multidimensional scaling analysis using the procedure ALSCAL. A two-dimensional solution yielded dimensions corresponding to (a) terrain flatness/verticality and (b) a composite of size, density, and spacing of scene elements. The only two A-10 pilots in the investigation weighted Dimension 2 much more heavily than did any other subjects. These results suggest that (a) efforts should be directed toward effectively modeling vertical features such as hills and ridge lines in simulator visual scenes; (b) a high density of small-scale and closely spaced scene elements (e.g., desert bushes) is less effective than larger-scale, more distinguishable scene elements (e.g., buildings); and (c) mission requirements for certain aircraft (e.g., the A-10) may place special emphasis on particular types of scene content.

Kleiss, J. A. (1990). Terrain visual cue analysis for simulating low-level flight: A multidimensional scaling approach. In E. G. Monroe (Ed.), Proceedings of the 1990 IMAGE V Conference (pp. 60-67). Tempe, AZ: IMAGE Society, Inc.

Multidimensional scaling was used to analyze the features of real-world terrain that are salient to pilots during low-level flight. Fifteen pilots rated the visual similarity of pairs of terrains depicted in short video segments. A two-dimensional multidimensional scaling solution yielded dimensions corresponding to (a) terrain flatness/verticality and (b) a composite of the size, density, and spacing of scene elements. The only two A-10 pilots in the investigation weighted Dimension 2 much more heavily than any of the other subjects. These results suggest (a) that efforts should be directed toward effectively modeling vertical features such as hills and ridge lines in simulator visual scenes; (b) although high scene element density is important, larger more discernible elements such as buildings may be more effective than small, closely spaced scene elements such as desert bushes; and (c) flight dynamics, tactics, and/or mission requirements for certain aircraft (e.g., A-10) may place special emphasis on particular types of scene content.

Kleiss, J. A. (1991). Multidimensional scaling analysis of terrain features relevant for simulating low-altitude flight. In Proceedings of the Human Factors Society 35th Annual Meeting (Vol. 2, pp. 1372-1376). Santa Monica, CA: Human Factors Society.

Multidimensional scaling was used to identify the features of real-world terrain that are salient to pilots during low-altitude, high-speed flight. Subjects were 10 U.S. Air Force and Air National Guard pilots experienced in low-altitude flight. The stimuli were 17 short (i.e., 5-s duration) videotape segments depicting low-altitude, high-speed flight over a variety of real-world terrains. Pilots rated pairs of terrains with respect to similarity of terrain features relevant for visual low-altitude flight. Similarity ratings were submitted to a multidimensional scaling analysis using ALSCAL. A two-dimensional solution revealed two dimensions corresponding to (a) the presence/absence of hills and ridges and (b) the presence/absence of large objects clustered into groups. Results suggests that designers of flight simulators should focus on representing hills and ridges, as well as and large trees and buildings, with high perceptual fidelity.

Kleiss, J. A. (1992). <u>Influence of operational factors on importance of scene properties for visual low-altitude flight</u> (AL-TR-1992-0158). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Previous research has identified two properties of visual scenes that are important to pilots during visual low-altitude flight: (a) variation in terrain contour mediated by presence or absence of hills and ridges and (b) variation in the conspicuity of objects mediated by size, spacing, contrast, and familiar appearance. The present experiment sought to determine whether operational factors influence the relative importance of scene properties. Five subject groups were used: F-16 pilots similar to those used in previous experiments, A-10 pilots, F-111 pilots, U.S. Air Force pilots with little or no operational low-altitude experience (inexperienced), and nonpilots. Results for F-16 pilots and nonpilots were similar to one another and replicated previous results. However, subtle differences in spatial configurations for these groups suggested differences in the relative importance of the scene properties. These results suggest that essentially the same scene properties are important to pilots regardless of operational experience. However, operational experience can affect the relative importance of scene properties in some cases.

Kleiss, J. A. (1992). <u>Perceptual dimensions of visual scenes relevant for simulating low-altitude flight</u> (AL-TR-1992-0011, AD-A254 645). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Multidimensional scaling was used to identify the features of real-world terrain that are salient to pilots during low-altitude flight. The subjects were pilots experienced flying in the Southwest United States (Experiment 1) and pilots experienced flying in Europe (Experiment 2). The stimuli were videotape segments (dynamic presentation) and still photographs (static presentation) depicting low-altitude flight over a variety of real-world terrains. Pilots rated pairs of terrains with respect to similarity of visual cues for low-altitude flight. Terrains were also rated on eight bipolar rating scales representing a variety of terrain characteristics thought to be of possible relevance to pilots. Similarity ratings were submitted to a multidimensional scaling analysis using the procedure ALSCAL. Two-dimensional solutions were deemed most appropriate in all cases. Bipolar ratings were submitted to a multiple regression analysis in which ratings on each scale were regressed over dimensional coordinates. Results of Experiment 1, dynamic presentation, revealed dimensions corresponding to (a) terrain contour and (b) object size and spacing. Results for static presentation were less interpretable, suggesting the possibility of a single dimension capturing the presence/absence of global scene detail. In Experiment 2, results for both presentation modes replicated Experiment 1, dynamic presentation, although the fit of the data remained superior with dynamic presentation. Taken together, these results provide consistent evidence that pilots flying at low altitudes perceive variation in terrain contour and object size and spacing.

Kleiss, J. A. (1992). Tradeoffs types of scene detail for simulating low-altitude flight. In Proceedings of 1992 IEEE International Conference on Systems, Man, and Cybernetics (Vol. 2, pp. 1141-1146). New York, NY: Institute of Electrical and Electronics Engineers.

The present investigation evaluated effects of three types of flight simulator visual scene detail on detection of altitude change. Results showed that the density of vertical objects in scenes and the presence of complex texture on terrain surfaces both had a positive, but somewhat independent, effect on performance. The level of detail of individual objects had no effect on performance. These results provide some guidance as to the most efficient use of image processing resources.

Kleiss, J. A. (1993). Properties of computer-generated scenes important for simulating low-altitude flight. In Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting (Vol. 1, pp. 98-102). Santa Monica, CA: Human Factors & Ergonomics Society.

Previous research indicates two properties of real-world scenes are important to pilots for visual low-altitude flight: (a) vertical development mediated by presence or absence of hills and ridges and (b) discrete objects exemplified by large objects or groups of objects. The present investigation sought to determine whether these scene properties can be represented with adequate perceptual fidelity in flight simulator visual scenes. The stimuli were 16 computer-generated scenes exhibiting variation in both properties described above. Subjects rated visual similarity of scenes with regard to properties useful for visual low-altitude night. Ratings were analyzed using multidimensional scaling. A 2-dimensional spatial configuration captured orderly variation in both scene properties. Unlike previous results using real-world scenes, discrete objects were relatively more important than vertical development in computer-generated scenes. Also, groups of trees were no more salient than randomly scattered trees in computer-generated scenes, thus properties important in real-world scenes can be effectively modeled in computer-generated scenes although some differences remain.

Kleiss, J. A. (1994). Effect of terrain shape and object grouping on detection of altitude change in a flight simulator. In Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting (Vol. 1, pp. 119-123). Santa Monica, CA: Human Factors and Ergonomics Society.

Multidimensional scaling (MDS) analyses of flight simulator visual scenes reveal that both shape of the terrain surface as well as spatial distribution of objects on the terrain are salient to pilots flying at low altitudes. MDS is based upon similarity ratings and it was deemed important to verify the relevance of these scene properties using a performance-based task in a flight simulator. The task was an ascent/descent discrimination task similar to that used in other flight simulation research. Terrain shape and elements on the terrain (texture and objects) were factorially manipulated. Presence of hills as well as spatial organization of objects on the terrain affected performance in some conditions. A positive effect of hills is noteworthy because hills did not extend above the horizon and therefore posed no vertical obstructions. Thus, they provide relevant information for perceiving altitude change apart from the role they may play in obstructing vision or navigation.

Kleiss, J. A., Curry, D. G., & Hubbard, D. C. (1988). Effect of three-dimensional object type and density in simulated low-level flight. In Proceedings of the Human Factors Society 32nd Annual Meeting (Vol. 2, pp. 1299-1303). Santa Monica, CA: Human Factors Society.

Three-dimensional objects placed on simulated terrain surfaces are particularly effective as cues for altitude in simulated low-level flight. To conserve the limited edge processing capacity of CIG systems, objects have typically been simple in shape and, therefore, fairly abstract in appearance. The present investigation sought to determine whether the apparent size of more detailed and familiar appearing objects (e.g., trees and bushes) serves as an additional cue for altitude in simulated low-level flight. Results showed no differences in performance between abstract objects and familiar objects. However, performance did improve with increases in object density, at least for some performance measures. These results suggest that CIG processing capacity may be most effectively utilized by increasing object density rather than individual object detail.

Kleiss, J. A., Curry, D. G., & Hubbard, D. C. (1989). Effect of three-dimensional object type and density in simulated low-level flight (AFHRL-TR-88-66, AD-A209 756). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Altitude control in simulated low-level flight improves significantly when three-dimensional objects are added to simulator visual scenes. However, the limited processing capacity of IGs may be used either to increase the density of objects at the expense of individual object detail and realism or to increase the detail of objects at the expense of object density. The present investigation sought to determine whether object density or object detail is the more important factor in simulated low-level flight. Three types of three-dimensional object were employed: (a) a control condition consisting of inverted tetrahedrons (i.e., the simplest possible three-dimensional shape); (b) highly detailed and realistic pine trees; and (c) a mixture of oak trees, pine trees, and bushes. The four levels of object density employed ranged from 3 objects/sq mile to 175 objects/sq mile. The task required a perceptual judgement to discriminate a change in altitude and a control action to reestablish the initial target altitude. Results indicated that object density had a greater effect on performance. Limited IG processing capacity may, therefore, be more effectively used by increasing object density rather than individual object detail.

Kleiss, J. A., & Hubbard, D. C. (1991). Effect of two types of scene detail on detection of altitude change in a flight simulator (AL-TR-1991-0043, AD-A242 034). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

The effect of two types of simulator scene detail on detection of change in altitude was evaluated. The first type was the density of three-dimensional objects in scenes, which ranged from 11 objects/sq mi to 175 objects/sq mi. The second was the detail/realism of three-dimensional

objects, which ranged from simple, untextured tetrahedrons (i.e., three-sided pyramids) to a mix of highly detailed and realistic appearing oak trees, pine trees, and bushes. A group of pilots and a group of nonpilots viewed short segments of flight over simulated terrains and responded by pushing one of three buttons to indicate whether they were descending, remaining level at 150-ft above ground level, or ascending. Results of Experiment 1 showed that accuracy and reaction times for both groups improved significantly with increases in object density. However, a significant effect of object type was obtained only for the nonpilot group with the accuracy dependent measures. Interestingly, the advantage favored tetrahedrons over realistic objects. In Experiment 2, these effects persisted even after four sessions of practice. These results suggest that available CIG processing capacity may be used most effectively by maximizing object density rather than object realism.

Kleiss, J. A., & Hubbard, D. C. (1993). Effects of three types of flight simulator visual scene detail on detection of altitude change. Human Factors, 35(4), 653-671.

The effects of three types of flight simulator visual scene detail on detection of altitude change were evaluated in three experiments. Across all experiments and with a variety of tasks and display conditions, speed and accuracy of detecting altitude change improved with increases in the density of vertical objects in scenes. Adding detail to individual objects to increase their natural appearance produced no consistent effects on performance. In Experiment 3, complex texture distributed globally on terrain surfaces improved detection of altitude change, but did not alleviate the need for high object density. These results indicate that available IG processing capacity would be used more effectively by increasing the density of objects in scenes rather than by increasing the complexity and detail of individual objects. Complex texture is used more effectively when distributed globally on terrain surfaces rather than when allocated to individual objects.

Kraft, C. L., & Anderson, C. D. (1980). Psychophysical criteria for visual simulations systems: Phase II - Experimental investigations of display joints and scene inserts (AFHRL-TR-80-18, AD-A088 316). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This report describes the approach, procedures, and results of two psychophysical experiments to provide data useful in developing design criteria for visual simulation systems. The first dealt with influence of the width of joints between display channels on the discrimination of vertical and rotational scene misalignment across the joint. The resulting information indicated that increasing amounts of rotation resulted in an increased percentage of correct detections. This anticipated result was not found for the displacement conditions. It was hypothesized that this unexpected result may have been caused by the counteracting effect of the Poggendorff visual illusion. The second psychophysical experiment dealt with the discrimination of rotational misalignment of scene inserts. Increasing insert size and increasing rotational misalignment produced increased detection performance. The 50% detection threshold occurred at 7 arc s of displacement between corresponding portions of the insert and surrounding scenes. Design tolerances based on these data are suggested.

Kraft, C. L., Anderson, C. D., & Elworth, C. L. (1980). Psychophysical criteria for visual simulation systems (AFHRL-TR-79-30, AD 084 776). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

We studied a prioritized list of psychophysical aspects of visual simulation systems for military flight training simulators. The available literature, operational experiences of simulator commands, and current research program data were assembled, organized, reviewed, evaluated, and summarized to provide psychophysical criteria for the visual displays subsystem. Areas of insufficient data were identified and seven experimental designs are suggested for psychophysical investigations to provide for some of the missing data.

Kruk, R., & Longridge, T. M. (1984). Binocular overlap in a fiber optic helmet mounted display. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 363-378). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Target detection, motion detection, and flight performance were compared under conditions of 25- and 45-deg binocular overlap using only the low-resolution background channels of an FOHMD. In Experiments 1 and 2, eight experienced fighter pilots viewed aircraft targets that either approached ownship or moved vertically in the FOV, respectively, at various angles of off-axis eccentricity. As an additional task, pilots flew the system as an air combat simulator and were required to track, engage, and destroy an airborne target. The results indicated target and motion detection and binocularly displayed targets were superior to that of monocularly displayed targets. There was no significant difference in target detection or motion detection between the two overlap conditions, per se, nor between left and right FOVs. In both overlap conditions, performance was degraded within 5-deg of the lateral edges of the FOV and suppression was evident in contralateral fields in the areas of optical frame overlap. However, the latter effects were combined nearer the central viewing area for the 25-deg overlap condition. No significant differences were noted in the supplementary air combat task as a function of overlap, but structured debriefing data indicated loss of target imagery is less of a problem with the larger overlap. It is concluded that greater than 25-deg binocular overlap should be utilized in follow-on systems.

Kruk, R., Regan, D., Beverley, K. I., & Longridge, T. (1981). Correlations between visual test results and flying performance on the Advanced Simulator for Pilot Training (ASPT). Aviation, Space, and Environmental Medicine, 52(8), 455-460.

Looking for visual differences in pilots to account for differences in flying performance, we tested five groups of subjects: U.S. Air Force primary jet (T-37) student pilots, graduating (T-38 aircraft) students, U.S. Air Force IPs, and two control groups made up of experienced nonpilot aircrew and nonflying civilians. This interim report compares 13 different visual test results with low-visibility landing performance in the ASPT. Performance was assessed by the number of crashes and by the distance of the aircraft from the runway threshold at the time of the first visual

flight correction. Our main finding was that for student pilots, landing performance correlated with tracking performance for a target that changed size as if moving in depth and also with tracking performance for a target that moved sideways. On the other hand, landing performance correlated comparatively weak with psychophysical thresholds for motion and contrast. For student pilots, several of the visual tests gave results that correlated with flying grades in T-37 and T-38 aircraft. Tracking tests clearly distinguished between the nonflying group and all flying groups. On the other hand, visual threshold tests did not distinguish between nonflying and flying groups except for grating contrast, which distinguished between the nonflying group and pilot instructors. The sideways-motion tracking task was sensitive enough to distinguish between various flying groups.

Kruk, R., Regan, D. M., Beverley, K. I., & Longridge, T. M. (1982). Visual channel sensitivity and pilot performance in a flight simulator. In R. E. Edwards & P. Tolin (Eds.), Proceedings of the Human Factors Society 26th Annual Meeting (pp. 885-889). Santa Monica, CA: Human Factors Society.

In previous research, significant correlations were found between measures of sensitivity in certain hypothetical visual channels and simulated landing performance under degraded visibility. The present study replicated the earlier findings and extended the approach to a broader cross section of flight tasks. An additional psychophysical test of superthreshold velocity discrimination was found to exhibit significant correlation with formation flight precision and with manual weapons delivery performance.

Kruk, R., Regan, D., Beverley, K. I., & Longridge, T. (1983). Flying performance on the Advanced Simulator for Pilot Training and laboratory tests of vision. Human Factors, 25(4), 457-466.

Simulator flying performance was compared with the results of sensory visual tests for student pilots, IPs, and fighter pilots; and aircraft flying grades were compared for student pilots. Simulator tasks were formation flight, low-level flight, bombing, and restricted-visibility landing; visual tests were superthreshold velocity discrimination of a radially expanding flow pattern, manual tracking of both motion in depth and motion in the frontal plane, motion thresholds and contrast thresholds for a moving square, and a static sinewave grating. Landing and formation flight performance correlated with both manual tracking and expanding flow pattern test results. Pilots who were better able to discriminate different rates of expansion of the test flow pattern achieved a greater percentage of hits and near misses in the low-level flight and bombing task. Aircraft flying grades for student pilots correlated with expanding flow pattern test results and with manual tracking of motion in depth. These findings suggest that tests of visual sensitivity to superthreshold motion might usefully be added to current selection tests for flying personnel. They also emphasize the importance of accurate, artifact-free representation of motion in simulator visual displays.

Kruk, R. V., & Runnings, D. W. (1989). Low level flight performance and air combat maneuvering performance in a simulator with a fiber optic helmet mounted display system. In AIAA Flight Simulation Technologies Conference and Exhibit, A Collection of Technical Papers (AIAA Paper No. 89-3287). Washington, DC: American Institute of Aeronautics and Astronautics.

The capability of an F-16C simulator equipped with an FOHMD was demonstrated by assessing pilot performance in target detection and identification tasks and flying tasks. Results are presented for performance in air-to-ground and air-to-air combat scenarios. Flying performance in a simulated hostile environment was studied under FOV conditions of 87, 107, and 127 deg. It was found that target detection and identification performance was better using a high-resolution field than a low-resolution field. The effect of reduced FOV on pilot performance and acceptance was shown to vary depending upon the demands and characteristics of the task being performed. In formation tasks, performance with stereo imagery was superior to that with nonstereo imagery.

Lee, A. T., & Hughes, R. G. (1981). Visual display resolution and contrast requirements for air combat simulation: An application of computer modeling. In Proceedings of the 3rd Interservice/Industry Training Equipment Conference and Exhibition (Vol. 1, pp. 33-40). Arlington, VA: American Defense Preparedness Association.

A study on the effects of target resolution and contrast in air combat engagements was conducted to determine the potential impact of visual display characteristics on the effectiveness of air combat simulation training. A large-scale computer model of air combat engagements was used to investigate the effects of 2 and 4 arc min of target resolution and target/background contrast ratios of 0.5 and 9.0. The study results are discussed in the context of the benefits of enhanced visual display characteristics in practicing the skills required in air combat.

Lee, A.T., & Lidderdale, I.G. (1983). Visual scene simulation requirements for C-5!/C-141B aerial refueling part task trainer (AFHRL-TP-82-34). Williams AFB, AZ: Operations Training Division. This report addresses the requirements of visual scene simulation for effective training in a ground-based aerial refueling part-task trainer.

Leinenwever, R. W., Best, L. G., & Ericksen, B. J. (1992). Low-cost color LCD helmet display. In T. M. Lippert (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1695, Helmet-Mounted Displays III (pp. 68-71). Bellingham, WA: SPIE-The International Society for Optical Engineering.

The present helmet-mounted display development effort has attempted to demonstrate the feasibility and capabilities of a low-cost color display that incorporates see-through optics and a head-tracking system for full field of regard. The color-imaging devices are 3-in.-diagonal LCD panels, and fiber-optic light panels mounted behind the LCDs furnish a cool light source. A beamsplitting function is incorporated into the optics to allow cockpit instrument viewing while revealing the out-of-window scene.

Leinenwever, R. W., Best, L. G., & Ericksen, B. J. (1992). Low-cost monochrome CRT helmet display. In T. M. Lippert (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1695, Helmet-Mounted Displays III (pp. 64-67). Bellingham, WA: SPIE-The International Society for Optical Engineering.

The present helmet-mounted display development involves the use of a low-cost monochrome CRT display in a way that incorporates see-through optics and allows the integration of various image generation systems for low-cost cockpit trainers and night vision goggle training applications. A major goal for this helmet-mounted display design was the furnishing of a full field of regard, using a head-tracker system. The helmet-mounted display system devised incorporates two 1-in. CRTs with beamsplitters and spherical mirrors.

Leinenwever, R. W., Best, L. G., & Ericksen, B. J. (1993). Low-cost helmet-mounted displays (AL-TR-1993-0008, AD-A262 616). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

This report contains two papers presented at the Helmet-Mounted Displays IV, International Symposium and Exhibition on Optical Engineering and Photonics, held at Orlando, FL, on 20-24 April 1992. This symposium was sponsored by the Society of Photo-Optical Instrumentation Engineers (SPIE). The papers describe the development and demonstration of two helmet-mounted displays: a low-cost monochrome helmet display and a low-cost color helmet display, both with see-through optics. The present monochrome CRT display helmet design, through demonstrations and system measurements, provided positive data as a research device. The color LCD helmet display system was successfully completed, and although the resolution of the LCD matrix structure is not suited for the application of small text in the presentation, the high contrast and vivid colors produced by the LCD, as well as the see-through function of the optics, provide the capability for a full-field-of-regard visual simulation system that can be used in conjunction with low-cost cockpit training devices.

Leinenwever, R. W., & Moran, S. I. (1992). Transport delay measurements: Methodology and analysis for the F-16C Combat Engagement Trainer, the Display for Advanced Research and Training, and the F-16A Limited Field of View (AL-TP-1992-0009, AD-A248 519). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Transport delays between the cockpit and visual/sensors in simulation systems can result in significant degradation of flight simulation training. At the Aircrew Training Research Division of the Armstrong Laboratory, methodologies for testing visible delays were developed and measurements run on three systems. The tests showed significant transport delays; in some cases, higher than anticipated. Further analysis of the data revealed that the delays were caused by specific hardware and software configurations. Changes in configurations can eliminate the problem entirely or can decrease transport delays to an acceptable range.

LeMaster, W. D., & Longridge, T. M., Jr. (1978). Area of interest/field-of-view research using ASPT (AFHRL-TR-78-11, AD-A055 692). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Two exploratory experiments were conducted in the ASPT to examine the head-slaved AOI approach for reduced FOVs employing CGI. The objective of Study 1 was to establish a suitable range of AOI sizes for simulated conventional gunnery range bombing performance. The results indicated an AOI size as small as 70-deg vertical by 90-deg horizontal could be usefully employed without seriously degrading bombing performance. The objective of Study 2 was to determine the effect of AOI level of detail on air-to-surface weapon delivery performance in a tactical environment. Study 2 also addressed the question of whether AOI size affected bombing performance in such an environment. No effects on bombing performance of either detail level, AOI size, or their interaction were observed. It was concluded from both studies that an AOI size as small as 70-deg vertical by 90-deg horizontal is feasible for the head-slaved AOI approach.

Lindenberg, K. W. (1982). Color television projection system using three cathode ray tubes (AFHRL-TP-82-5, AD-A114 828). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The purpose of this project was to provide for the design, development, and fabrication of advanced simulation systems in order to test and demonstrate their performance capabilities. These tests and demonstrations will be used to establish the technical feasibility, as well as the performance characteristics, of systems that might be used in operational simulators in future years. The work described in this report applies to the area of visual simulation.

Lindholm, J. M. (1992). Temporal and spatial factors affecting the perception of computer-generated imagery (AL-TR-1991-0140, AD-A249 242). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

When CGI is presented on a raster display device, the spatiotemporal representation of a given dynamic scene varies with the update of the IG and the refresh pattern of the display device. The effects of these variables on form perception were examined in three experiments. In Experiment 1, observers were instructed to maintain a steady fixation during 267-ms motion sequences. Target shape, target velocity, image update rate, and raster pattern were varied orthogonally. Identification responses indicated that the temporal interval between successive fields of an interlaced display tended to be perceived as a spatial interval. The probability and extent of this temporal-to-spatial conversion declined as target velocity increased. In Experiment 2, observers were instructed to track the target in 30-Hz interlaced displays of three durations (i.e., 133, 267, and 533 ms). Under these conditions, complete temporal-to-spatial conversion was the predominant percept for all velocities (i.e., 4.7 to 18.8 deg/s) at the longest sequence duration. In Experiment 3, observers were instructed to track the target in noninterlaced displays. Sequence duration (i.e., 267, 533, 800, and 1067 ms), image update rate (i.e., 15, 30, and 60 Hz), target velocity (i.e., 4.7, 9.4, and 14.1 deg/s) and direction of target-surround contrast (i.e., dark on light, as in Experiments 1 and 2, and light on dark) were varied.

Lindholm, J. M., Askins, T. M., & Krasnicka, K. (1993). Image update rate and apparent self-motion speed. In J. Morreale (Ed.), 1993 SID International Symposium Digest of Technical Papers, Volume XXIV (pp. 506-509). Playa del Rey, CA: Society for Information Display.

The update rate of an IG affects the spatiotemporal representation of a time-varying scene and thus, potentially, an observer's percept during observation of the display image. We examined the effects of update rate (i.e., 30 versus 60 Hz) on the apparent speed of self-motion over textured terrain. The results suggest that update rate can affect the perception of speed when the temporal frequencies in the continuous image (i.e., internal to the computer) are relatively high.

Lindholm, J. M., & Martin, E. L. (1993). Effect of image update rate on moving target identification range (AL-TR-1992-0172, AD-A261 562). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

In prior research, moving-form perception tended to be nonveridical when the update rate of an IG was less than the refresh rate of the display device. In this experiment, we examined the effect of update rate on the range at which pilots could identify computer-generated representations of moving aircraft. For a 60-hz interlaced display, identification range was greater for a 60-hz image update rate than for a 30-hz update rate. This effect held for two views of three pairs of aircraft moving at two different velocities. These results suggest that image update rate is an important design parameter for simulators intended to support air-to-air combat training. To maximize the range at which a moving target can be identified, the update rate of the IG should equal the refresh rate of the display device.

List, U. H. (1983). Nonlinear prediction of head movements for helmet-mounted displays (AFHRL-TP-83-45, AD-A136 590). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

In head- and eye-slaved visual systems, lag times in the visual feedback loop are more apparent than they are in conventional fixed-display systems. The available technology of digital IGs does not permit lag times to be reduced to the required amount. Therefore, appropriate prediction algorithms have to be developed. Accelerometers were used to measure the step response of the head in three axes of rotation. It was shown that linear prediction did not provide the necessary accuracy in the simulated position. A further analysis of the recorded data revealed that it is possible to take advantage of the head's latency to improve the prediction. A simple nonlinear prediction algorithm based on acceleration data was successfully implemented in the FOHMD.

Longridge, T. M., & Dohme, J. A. (1988). Low cost visual flight simulator testbed. In Proceedings of the 10th Interservice/Industry Training Systems Conference (pp. 372-379). Arlington, VA: National Security Industrial Association.

A testbed program for the evaluation of low-cost flight simulator CIG systems is described, which employs a pragmatic approach based on simulator-to-aircraft transfer of training within the formal curricula for institutional flight instruction. The results of the first research study with this testbed, utilizing a CIG source that can reasonably be considered to represent a starting point along the low-cost continuum, are presented. The results were encouraging with respect to positive transfer of training achievable with low-cost technology.

Longridge, T., Thomas, M., Fernie, A., Williams, T., & Wetzel, P. (1989). Design of an eye slaved area of interest system for the simulator complexity testbed. In Proceedings of the 11th Interservice/Industry Training Systems Conference (pp. 275-283). Arlington, VA: American Defense Preparedness Association.

The Simulator Complexity Testbed (SCTB) is a highly modular flight simulator for experimental research focused on U.S. Army Aviation advanced rotary-wing combat. A major component in the development of the helmet-mounted, fiber-optic display media for this device is an eye-slaved AOI. In order to provide for an accurate, reliable, and robust helmet-mounted eye tracker to support proper system operation, the engineering development of competing eye-tracking designs was initiated under a cooperative U.S. Army/U.S. Air Force/Canadian cost-shared development program. This paper describes the overall design of the SCTB eye-slaved, servo-driven optical system and discusses the issues involved in its development.

Magarinos, J. R., & Coleman, D. J. (1981). Wide angle, color, holographic infinity optics display (AFHRL-TR-80-53). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This project demonstrates the feasibility of producing a holographic compound spherical beamsplitter mirror with full-color response. Furthermore, this holographic beamsplitter was incorporated into a Pancake Window display system as a replacement for the classical glass spherical beamsplitter, and its performance and color capabilities have been demonstrated.

Magarinos, J. R., Coleman, D. J., & Lenczowski, T. (1981). Low cost, wide angle infinity optics visual system (AFHRL-TR-80-54, AD-A105 508). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Holographic beamsplitter spherical mirrors have been introduced in the Pancake Window visual simulators as a low-cost and low-weight substitute for the classical glass beamsplitter spherical mirrors. The goal of this project was the production of a three-channel visual simulator consisting

of a mosaic of three holographic Pancake Windows in which these beamsplitter spherical mirrors are used. The FOV of the complete display is 45-deg vertical by 140-deg horizontal, and the display will be used to demonstrate a dynamic, unprogrammed visual simulation imagery generated by TV camera-model and gantry IG. Prior to the production of the holograms, holographic research was carried out to investigate and resolve problems that have affected the quality and the repeatability of the final product. Specific attention was given to holographic ghost images that seriously impaired the contrast and the resolution of the images produced by the holographic Pancake Window and to the effects of environmental controls. The final production of the holographic beamsplitter was delayed by a stability problem in the wet cell used to support the holographic plate during the holographic exposure. The phosphors in the CRT displays were originally designed to be P-44 narrow-band phosphors but were later changed to a wide-band emission phosphor. The reason for this was a wavelength peak response shift of the holograms with large FOV angles. The use of a wide-band phosphor, although it penalized the transmission of the holographic Pancake Window, required less stringent wavelength peak location in the manufacture of these holographic beamsplitter mirrors.

Malone, H. L., III, Horowitz, S., Brunderman, J. A., & Eulenbach, H. (1987). The impact of network delay on two-ship air-to-air combat simulation. In AIAA Flight Simulation Technologies Conference, A Collection of Technical Papers (AIAA Paper No. 87-2373, pp. 55-58). New York, NY: American Institute of Aeronautics and Astronautics.

The maximum tolerable transport delay between simulators, the between-simulator transport delay, is defined for a two-ship engagement using Air Combat Maneuvering Instrumentation (ACMI) data. The ACMI data were replayed on an IRIS video monitor, which provided images of the engagement as seen out-the-window from the attacker's cockpit. The images provided by IRIS were frozen at times of interest during the engagement, allowing an assessment of the relative positions of the aircraft using pilot evaluations. The results of this experiment provide the designers of networked simulators a guide as to the amount of between-simulator transport delay that can be tolerated and the effect of prediction algorithms.

Martin, E. L., & Cataneo, D. F. (1980). Computer generated image: Relative training effectiveness of day versus night visual scenes (AFHRL-TR-79-56, AD-A088 313). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

A transfer-of-training design was used to compare the relative training effectiveness of day and night visual scenes for the acquisition of takeoff and landing skills in the novice pilot in daylight flight conditions. Twenty-four undergraduate pilot trainees with no previous jet piloting experience were randomly assigned to one of the three treatment groups ($n = 8$): Day, Night, and Control. Those students assigned to the Control group received the standard syllabus of preflight and flightline instruction. The students in the two experimental groups received three sorties in the ASPT covering instruction of takeoff, straight-in approach and landing, and straight-in approach to

a touch-and-go. ASPT-trained students received the same amount of training on each task with performance evaluated periodically with the ASPT's automated performance measurement system, as well as with performance ratings supplied by the IP. The only difference in training conditions was the use of either a day or night runway environment visual scene. The FOV of the visual display was limited by a computer mask to 48-deg horizontal by 36-deg vertical. Following completion of the ASPT training, the students advanced to the flightline for T-37 instruction. Transfer-of-training evaluation data were collected by the student's IP on the second and fifth T-37 missions. All IPs had received thorough pretraining in the ASPT on the data collection procedures. The data protocol called for at least one repetition of each of the three tasks on each flight. The IP was to record specific aircraft system states of various task segments as well as provide overall task proficiency grades. The findings of the study were as follows. (a) There were no overall differences between the Day and Night groups in their simulator performance, although there was a transitory superiority of the Day group on control of glidepath descent angle. (b) There were no differences between the Day and Night groups in their performance in the aircraft. (c) The two experimental groups performed reliably better than the Control group on the takeoff task. The results of this study, when integrated with the findings of other relevant research, indicate that while positive transfer of training to daylight flight can be expected with the use of either a day or night computer-generated display, simulator training should be more extensive than used in the present study and follow-up data on student performance should be collected.

Martin, E. L., & Lindholm, J. M. (1992). Effects of image update rate on target identification range. In <u>Proceedings of the Thirteenth Symposium Psychology in the Department of Defense</u> (USAFA TR 92-2, pp. 178-182). Colorado Springs, CO: Department of Behavioral Sciences and Leadership, U.S. Air Force Academy.

In prior research, moving-form perception tended to be nonveridical when the update rate of an IG was less than the refresh rate of the display device. In this experiment, we examined the effect of update rate on the range at which pilots could identify moving aircraft models. The results indicated that target identification range is greater for a 60-hz update rate than for a 30-hz update rate. Methodological issues and flight simulation design implications are discussed.

Martin, E. L., & Rinalducci, E. J. (1983). <u>Low-level flight simulation: Vertical cues</u> (AFHRL-TR-83-17, AD-A133 612). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This report presents the results of two studies investigating the impact of variations in vertical cue characteristics on pilot performance on a simulated low-level flight task. The studies were conducted in the ASPT in its F-16 configuration. Subjects were pilots transitioning to the F-16 aircraft. The experimental task consisted of flying a course that had irregularly placed vertical cues. The pilots' task was to maintain an assigned altitude and airspeed. The pilots' ability to maintain the specified altitude was analyzed for level flight and turning flight. The frequency of terrain crashes was also monitored.

McCollough-Howard, C. (1993). Device-independent color rendering for multiple display devices and networked simulator displays. In J. Morreale (Ed.), 1993 SID International Symposium Digest of Technical Papers, Volume XXIV (pp. 569-572). Playa del Rey, CA: Society for Information Display.

Data on color-matching procedures for multiple-device displays employing projection CRTs, LCD projectors, or Talaria light-valve projectors indicate that color control based on the CIE system has advantages for simulator displays. Among these advantages is the opportunity to derive XYZ values directly from physical data.

McCormick, D., Smith, T., Lewandowski, F., Preskar, W., & Martin, E. (1983). Low-Altitude Database Development Evaluation and Research (LADDER). In Proceedings of the 5th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 150-155). Arlington, VA: American Defense Preparedness Association.

Singer-Link and the Air Force Human Resources Laboratory combined efforts to investigate specific visual requirements during low-level, high-speed flight. Visual information requirements were hypothesized, and an experiment was designed to systematically test the effects of various visual cues upon flight performance. The experiment tested the effects of visual scene elements in supporting simulator flight tasks of experienced U.S. Air Force fighter pilots. Specific visual factors studied were: (a) the importance of surface texture, (b) the importance of three-dimensional objects and object type, and (c) the effect of turning and bank angle upon flight performance. Pilot subjects were able to control flight at a mean altitude of 198 ft and at an airspeed of 480 knots. Test results indicate that both three-dimensional objects and two-dimensional terrain surface texture aid controlled low-altitude flight.

Miller, M. (1984). Using a limited field of view simulator to instruct high speed, low altitude flying skills. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 7-20). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This paper describes the use of an A-7 Vital IV visual simulator in a low-altitude training program. This program is the first to use such a simulator in the training of tactical fighter pilots to operate in the low-altitude environment. The program is part of the syllabus used in the Air National Guard Fighter Weapons School program for highly experienced A-7D pilots. The Low Altitude Training portion of this syllabus consists of 12 hr of academic instruction, a 1-hr simulator exposure, and a two-phase flying program of at least two aircraft sorties. This paper discusses the simulator profile, explains each task, how it is accomplished, and provides a subjective evaluation of its effectiveness. The paper identifies the training limitations imposed by such a low-fidelity visual system, recommends several additional uses within the existing capability of the simulator, and identifies several minimum criteria for any full-mission simulator.

Miller, R. H. (1978). Advanced Simulator for Pilot Training (ASPT): Refinement of environmental database generation system (AFHRL-TR-78-55, AD-A059 857). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

This report documents the current status of the visual database generation system and the improvements of the software that have been made since delivery of the system.

Monroe, E. G. (1975). Computer image generation (CIG) in visual flight simulation. In Proceedings of the Sixth Annual Pittsburgh Conference, Modeling and Simulation, Volume 6, Part 1 (pp. 475-477). Pittsburgh, PA: Instrument Society of America.

The CIG visual research flight simulator at Williams Air Force Base is described. The visual environment, defined in three-dimensional vector space and stored as numerical data on two computer fixed-head disks, can contain a maximum of about 40,000 objects, 5,000 models, and 300,000 edges. The computational system consists of two general-purpose computers and a special-purpose computer with 152,000 32-bit words of dedicated core memory. The display system incorporates special optics and CRT electronics producing a highlight brightness of 6 fL and a resolution of 6 arc min. 36-in. monochrome CRTs and the infinity optics form seven pentangular faces out of a regular dodecahedron and surround the cockpit to form the visual display. The system operates in real-time projection on a two-dimensional perspective display screen in response to an unrestricted viewpoint, position, and attitude.

Monroe, E. G. (1975). Environmental data base development process for the ASUPT CIG system (AFHRL-TR-75-24, AD-A017 845). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

This report was prepared under the assumption that the reader has a general understanding of the ASUPT CIG system. Modeling for CIG may be thought of as a new art form in which the features to be modeled are approximated by sets of straight line segments forming planar faces to which a shade of gray is assigned. Basically the database is structured in the sequence edge, face, object, model, and environment, each item composed of a set of the items immediately preceding it in the sequence. The detailed definition of each item is transferred from the coding forms prepared by the modeler to computer input cards. These cards serve as the computer source input. The offline software algorithms perform validation checks on this input. Error message are related through the teletype and line printer. Valid data are stored as libraries of objects, models, and environments on magnetic tapes, and the appropriate environment is restored on disk by a media conversion from tape to disk.

Monroe, E. G. (1976). Air-to-surface full mission s imulation by the ASUPT system. In Proceedings of the 9th NTEC/Industry Conference (NAVTRAEQUIPCEN IH-276, pp. 41-48). Orlando, FL: Naval Training Equipment Center.

Air-to-surface weapons delivery is one realm of visual flight simulation that has been rather neglected until recent investigations were made by the U.S. Air Force to determine the state of the art in this area. As part of this investigation (i.e., Project 2235, Air-to-Ground Visual Evaluation), the ASUPT system was expanded to include the additional capabilities required to perform air-to-surface weapons delivery. Evaluations of the various systems under consideration have shown the ASUPT CIG approach to air-to-surface visual simulation to be the most viable. This paper summarizes the engineering modifications made to the ASUPT system for Project 2235 and presents the operational capabilities of the new system configuration.

Monroe, E. G. (1976). Air-to-surface weapons delivery simulation with a computer-image generation system. In W. G. Vogt & M. H. Mickle (Eds.), Modeling and Simulation, Volume 7, Part 1, Proceedings of the Seventh Annual Pittsburgh Conference (pp. 526-530). Pittsburgh, PA: Instrument Society of America.

Air-to-surface weapons delivery has been virtually unexplored as far as visual flight simulation is concerned. The capability of CIG to simulate visual weapons delivery applications has been successfully demonstrated by a reconfiguration of the advanced research flight simulator known as the ASUPT. The technical hardware and software modifications made to the system are summarized, and the operational results of the new configuration are presented.

Monroe, E. G. (Ed.). (1977). Proceedings of the 1977 IMAGE Conference (AD-A044 582). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

This conference concerns issues relevant to the development and use of imagery generated and displayed for visual flight simulation. The purpose of the conference is to provide a forum for presenting and discussing topics concerned with the imagery generated for out of the cockpit and sensor visual flight simulation. The conference encompassed 20 technical papers. Topics addressed in the papers included (a) efficient and effective modeling techniques, (b) environmental database design and structure, (c) psychological determination of visual cue requirements, and (d) software/hardware developments directly resulting in an expansion of image capability and/or utility.

Monroe, E. G. (Ed.). (1981). Proceedings of the 1981 IMAGE II Conference (AFHRL-TR-81-48, AD-A110 226). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This conference concerns issues relevant to the development and use of imagery generated and displayed for visual flight simulation. The purpose of the conference is to provide a forum for presenting and discussing topics concerned with the imagery generated for out of the cockpit and sensor visual flight simulation. The conference encompassed 31 technical papers. Topics addressed in the papers included (a) software/hardware developments directly resulting in an enhancement of image capabilities, (b) psychological determination of visual cue requirements, and (c) environmental database design and structure.

Monroe, E. G. (Ed.). (1984). Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This conference concerns issues relevant to the development and use of imagery generated and displayed for visual flight simulation. The purpose of the conference is to provide a forum for presenting and discussing topics concerned with the imagery generated for out of the cockpit and sensor visual flight simulation. The conference encompassed 31 technical papers. Topics addressed in the papers included (a) software/hardware developments directly resulting in an enhancement of image capabilities, (b) psychological determination of visual cue requirements, and (c) environmental database design and structure.

Monroe, E. G., Mehrer, K. I., Engel, R. L., Hannan, S., McHugh, J., Turnage, G., & Lee, D. R. (1978). Advanced Simulator for Pilot Training (ASPT): Aerial refueling visual simulation - engineering development (AFHRL-TR-78-51, AD-A063 283). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

This report documents the engineering modifications made to the ASPT to expand its capability to include aerial refueling simulation. These modifications include the generation of a number of KC-135 tanker models in various levels of image detail, refueling boom, and director lights. The existing variable/slewable FOV program was modified to generate multiple window configurations. The on-line programs were amended to provide boom dynamics, operational director lights, and tanker flow field effects. Performance measurement techniques and a dynamic graphics display were programmed to provide an adequate means of assessing and monitoring pilot performance.

Monroe, E. G., & Richeson, W. E. (1977). CIG edge conservation evaluation and application to visual flight simulation. In Proceedings of the 10th NTEC/Industry Conference (NAVTRAEQUIPCEN IH-294, pp. 157-168). Orlando, FL: Naval Training Equipment Center.

This paper addresses a new approach to the visual scene presentation within a wide-angle optical mosaic display of CGI and a means of determining and analyzing the visual system processing and display capacities being utilized. An AOI presentation concentrates visual detail in that portion of the entire display to which the pilot's immediate attention is directed. The AOI transverses the display in real time in coordination with the movement of the pilot's head. The result is a more efficient and effective utilization of system processing capacities, which can be measured with the system's visual parameter monitor. An operational description of the visual parameter monitor and AOI, together with an example of their integrated application, constitutes the body of this report.

Monroe, E. G., Rife, R. W., Cyrus, M. L., & Thompson, L. C. (1976). ASUPT visual simulation of air-to-surface weapons delivery (AFHRL-TR-76-40, AD-A034 319). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

The original configuration of the ASUPT system was designed to support research in undergraduate pilot training. This report describes the addition of an air-to-surface weapons delivery capability to the system. Provision is made for the delivery of a simulated M-117 bomb and strafe by a 30mm cannon. Information as to the accuracy of the ordnance delivery is presented to the pilot and observer in a number of ways. Immediate feedback is provided by the visual display of the ordnance ground impact points. If a three-dimensional feature is hit, it disappears from the display scene. Special graphics displays provide scoring for selected targets, aircraft parameters at time of release, and real-time monitoring of the aircraft's maneuvers. A special environment database was designed and developed that includes an airfield, gunnery range, and two tactical complexes. Special features include SAMs, moving ground target, lead/FAC aircraft, AAA, flak, etc. Significant algorithm and software program development was required to produce the visual ground impacts and provide trajectories/paths for the ordnance, SAMs, and moving ground target. To accommodate the additional software, 8K of core memory and a moving head disk drive were purchased and installed. Other hardware modifications included the acquisition of an optical gunsight and the activation of the stick trigger.

Moran, S. I., & Kornovich, W. M., Jr. (1992). Advanced network technologies for visual research. In E. G. Monroe (Ed.), Proceedings of the 1992 IMAGE VI Conference (pp. 114-121). Tempe, AZ: IMAGE Society, Inc.

What are the network requirements for training effectiveness? At the Aircrew Training Research Division of the Armstrong Laboratory, a dynamically developing fight simulation network is providing an invaluable testbed for establishing design parameters that will support crewstation research. The network, composed of dissimilar systems, was designed with SIMNET architecture,

modified to support a tactical environment. The visual and display systems mix, including helmet-mounted displays and sensor correlation, was based on visual cue requirements for specific mission tasks. As the network is developing, performance parameters were set and baselined with an end-optimum configuration designed to support the specific mission and tactical requirements.

Nadel, J. I., & Warner, H. D. (1988). A human factors evaluation of the Visual System Component Development Program (VSCDP) eye-tracking system. In Proceedings of the IEEE 1988 National Aerospace and Electronics Conference, NAECON 1988 (Vol. 3, pp. 915-917). New York, NY: Institute of Electrical and Electronics Engineers.

Results of a qualitative human factors evaluation, conducted to identify the user, equipment, and environmental factors that impaired the performance of the Visual System Component Development Program eye-tracking system, are presented. The evaluation was performed in two phases: an exploratory phase and a validation phase. The results of the first phase indicated that eye-tracking performance was directly related to pupil size. In the second phase, the eyes of two subjects were chemically dilated and a profound improvement in eye-tracking performance was observed.

Nataupsky, M., Waag, W. L., Weyer, D. C., McFadden, R. W., & McDowell, E. (1979). Platform motion contributions to simulator training effectiveness: Study III - Interaction of motion with field-of-view (AFHRL-TR-79-25, AD-A078 426). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

The objective was to determine the effects of platform motion cuing, visual FOV, and their interaction upon learning in the simulator and subsequent transfer of training to the aircraft for basic contact maneuvers in the T-37 aircraft. A transfer-of-training study design was used in which student pilots were initially trained in the ASPT and subsequently evaluated on their first sortie in the T-37 aircraft. Each student received training under one of four simulator configurations: (a) full platform motion (i.e., six DOF), full FOV (i.e., 300-deg horizontal by 150-deg vertical); (b) full platform motion, limited FOV (i.e., 48-deg horizontal by 36-deg vertical); (c) no platform motion, full FOV; and (d) no platform motion, limited FOV. For the ASPT pretraining phase, scores from the automated performance measuring system and overall IP ratings were used for analysis. For the T-37 evaluation sorties, the overall IP ratings, as well as individually recorded flight parameters, were analyzed. These data provided no conclusive evidence of differential transfer effects resulting from platform motion cuing, size of the visual FOV, or their interaction. As such, these data provide support for previous findings that platform motion cuing does not significantly enhance the transfer of learning for basic contact tasks in the T-37 aircraft. It would seem that the impact of peripheral visual cues for initial acquisition is not critical. Furthermore, no convincing evidence was found indicating increased transfer using platform motion in conjunction with a narrow-FOV visual scene.

Owen, D. H. (1984). Optical flow and texture variables useful in detecting decelerating and accelerating self-motion (AFHRL-TP-84-4, AD-A148 718). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The two experiments presented in this report are part of a program that has the goals of mathematically isolating global optical candidates for self-motion information and of empirically assessing their usefulness. The first experiment tested sensitivity to loss in speed and demonstrated that (a) increasing fractional loss was easier to detect than invariant fractional loss; (b) the optimal optical texture density was one ground unit per eyeheight (altitude unit); (c) optimal combinations of flow deceleration and flow rate were found, but differ slightly with level of fractional loss in flow rate; and (d) males were more accurate than females. The second experiment separated flow-rate and edge-rate variables and tested for sensitivity to gain in speed with the following results: (a) sensitivity to flow-rate gain was independent of sensitivity to edge-rate gain; (b) the influences of initial flow rate and initial edge rate were independent; (c) sensitivity to edge-rate gain increased with event duration; (d) illusory edge-rate information was more salient than veridical flow-rate information; and (e) some individuals were more flow-rate dependent, some more edge-rate dependent, but no sex difference was observed. Theoretical implications for the ecological approach to the study of perception and for the study of information-specifying mechanisms are discussed.

Owen, D. H. (1985). Optical and event-duration variables affecting self-motion perception (AFHRL-TP-85-23, AD-A161 836). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This paper includes four experiment sections. The first pair of experiments investigated the usefulness of optical flow acceleration in detecting descent. When sink rate and ground speed are constant, optical flow accelerates. Holding fractional loss in altitude constant throughout a descent event also holds flow rate invariant, eliminating flow acceleration as a potential source of information. Detection of descent was accomplished easily without flow acceleration, and it was found that at least one of the remaining functional optical variables specifying fractional loss in altitude must be highly salient. Also, the effect of optical texture density was optimal when linkages with other relevant variables were taken into account. The third experiment compared eyeheight and ground-unit size as metrics for global optical information specifying descent. Given that flow acceleration is not an essential source of information, the study focused on eyeheight-scaled change in optical splay and ground-unit-scaled change in optical density as functional specifiers of fractional loss in altitude. The fourth experiment investigated the interaction between global optical flow rate and duration of a constant-speed preview period. Of particular interest was the possibility that preview periods of different durations would differentially favor or interfere with sensitivity given particular optical conditions, e.g., different flow rates. The results indicate that this is a complex issue. The fifth experiment assessed the effect of preview period on sensitivity to different fractional losses in altitude. Preview periods ranging from 1.25 to 5 s may interfere with sensitivity to change in speed and altitude in a fashion that produces a speed versus accuracy tradeoff.

Owen, D. H., Freeman, S. J., Zaff, B. F., & Wolpert, L. (1987). Perception and control of simulated self motion (AFHRL-TR-87-16). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This report includes three experiment sections. The first experiment tested sensitivity to loss in altitude and demonstrated that: (a) preview effects led to adaptation, (b) sensitivity decreased with higher flow rates, and (c) sensitivity increased with higher optical texture densities and fractional loss. The second and third experiments examined the perception and control of change in forward speed and altitude, respectively. Results from the former indicated that higher levels of fractional loss led to enhanced control of a constant speed, whereas high flow and/or edge rates interfered with performance. The control of altitude change was similarly affected by the levels of fractional loss, but the negative effect of flow rate occurred only in conditions of descending flight. Theoretical implications for the ecological approach to the study of perception and control are discussed.

Peppler, P. W., & Gainer, J. C. (1993). A full-color, high-resolution laser projector for a flight simulator visual display (AL-TR-1993-0120, AD-A270 578). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Laser projection is a promising approach to solving many of the shortcomings associated with current flight simulator projection methods. The advantages of laser projection were investigated and are discussed. The characteristics of light-valve, CRT, LCD, and laser projectors are compared. It was found that laser projection offers many benefits over current projection technology. Laser projection promises an increased color gamut, higher luminance, zero persistence, and increased line rate. The technology required to develop an efficient, cost-effective laser projector was researched and is described. Recent advances in laser diodes, solid-state diodes, and other rapidly developing technologies and techniques promise new territory for laser projection. It is concluded that laser projection is a promising solution to the shortcomings of flight simulator visual displays and that the technology now exists to develop an efficient, cost-effective laser projector.

Peppler, P. W., & Gainer, J. C. (1994). A full-color, high-resolution laser projector for a flight simulator visual display. In N. Jackson & N. Cruz (Eds.), 5th ITEC, International Training Equipment Conference and Exhibition Proceedings (pp. 112-129). Warminster, Wiltshire, UK: ITEC Ltd.

Laser projection is a promising approach to solving many of the shortcomings associated with current flight simulator projection methods. The advantages of laser projection were investigated and are discussed. The characteristics of light valve, CRT, LCD, and laser projectors are compared. It was found that laser projection offers many benefits over current projection technology. Laser projection promises an increased color gamut, higher luminance, zero persistence, and increased line rate. The technology required to develop an efficient, cost-effective

laser projector was researched and is described. Recent advances in laser diodes, solid-state diodes, and other rapidly developing technologies and techniques promise new territory for laser projection. It concludes that laser projection is a promising solution to the shortcomings of flight simulator visual displays and that technology now exists to develop an efficient, cost-effective laser projector.

Phelps, M. (1984). Low altitude texture comparison data base and smooth shaded texture (AFHRL-TP-84-33, AD-A150 342). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Various methods have been used to apply texture to computer-image ground terrain. This texture most often resembles a checkerboard or plaid pattern of multicolored squares that spread along the path of flight. With such texturing, low-level flight becomes much easier. Though checkerboard texture patterns make it possible to fly close to the ground, they add nothing to the realism of the scene and become monotonous after such a short time. The F-111 Digital Image Generator (DIG) visual system has a smooth shading algorithm that can be used to create terrain texture of a different sort. Smooth shading varies the intensity of the colors on the ground in a random fashion to produce texture that is more pleasing to the eye and more natural in appearance than regular predictable checkered patterns. It has not yet been determined whether this new texturing scheme is more effective in furnishing the needed visual cues for low-altitude flight. The aim of this paper is to document the techniques used to create smooth shaded texture on the DIG and to describe the layout of a database constructed for the purpose of comparing its effectiveness to that of a plaid, checkerboard-type of texture known as gingham texture.

Pierce, B. J., Felber, A. A., & Wetzel, P. A. (1993). Real image display effects on oculomotor response and the perception of spatial relationships. In J. Morreale (Ed.), 1993 SID International Symposium Digest of Technical Papers, Volume XXIV (pp. 502-505). Playa del Rey, CA: Society for Information Display.

A test facility has been established to examine the effects simulator display factors have on oculomotor response and perception of spatial relationships. Results of initial evaluations of laboratory equipment are described. Oculomotor response and results of a size matching task for static stimuli presented on displays at varying distances from eyepoint are presented.

Platt, P. A., Dahn, D. A., & Amburn, P. (1991). Low-cost approaches to virtual flight simulation. In Proceedings of the IEEE 1991 National Aerospace and Electronics Conference, NAECON 1991 (Vol. 2, pp. 940-946). New York, NY: Institute of Electrical and Electronics Engineers.

An attempt was made to determine whether a flight simulator could be hosted on inexpensive IGs and interfaced to a virtual environment system. Effective training systems provide a wide visual FOV through the use of CRT arrays or dome simulator projectors. These display systems

require graphics processing support from expensive IGs with multiple graphics channels. A promising technology that could help reduce the costs of these flight simulators is head-mounted display systems. Simple virtual world interfaces using head-mounted display technology require only one graphics channel, providing the potential to use low-cost IGs. The approach was to build a virtual world interface to an existing flight simulator application using a head-mounted display. To investigate two classes of computing platforms suitable for use as the IG, the flight simulator was hosted on a Silicon Graphics IRIS 4D/85GT and an 80386/80387 enhanced with a high-performance graphics engine. Neither the IRIS 4D/85GT system nor the personal computer system achieved the desired frame rate.

Regan, D. M., Kruk, R Beverley, K. I., & Longridge, T. M. (1981). The relevance of channel theory for the design of simulator imagery. In E. G. Monroe (Ed.), Proceedings of the 1981 IMAGE II Conference (AFHRL-TR-81-48, AD-A110 226, pp. 307-344). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

There is some experimental evidence supporting the hypothesis that an early stage of visual processing consists of analyzing retinal image information into a number of abstract categories or features called channels. This paper reviews the channel hypothesis and cites potential implications for flight simulator visual display design. Results of a preliminary study designed to investigate relationships between channel sensitivity and flight simulator landing performance are presented.

Regan, D., Kruk, R., Beverley, K., & Longridge, T. (1981). A visual channel theory approach to pilot performance and simulator imagery. In R. C. Sugarman, A. S. Baum, J. L. Ditzian, D. J. Funke, V. J. Gawron, & K. R. Laughery (Eds.), Proceedings of the Human Factors Society 25th Annual Meeting (pp. 223-227). Santa Monica, CA: Human Factors Society.

The hypothesis that an early stage of visual processing consists of analyzing retinal image information into a number of abstract categories or features, called channels, is reviewed, and the implications of this hypothesis for flight simulator visual display design are examined. The results of a study designed to evaluate relationships between channel sensitivity and flight simulator landing performance are presented. No statistically significant differences in any threshold measures were found between the nonflying group and any of the flying groups, although the in-phase tracking test distinguished the nonflying group from all flying groups. In addition, it was determined that tracking performance related most closely to low-visibility landing performance on the simulator.

Reid, G. B., & Cyrus, M. L. (1977). Formation Flight Trainer evaluation for T-37 UPT (AFHRL-TR-77-23, AD-A043 197). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

The present research was conducted to provide a preliminary look at the feasibility of using a general-purpose trainer rather than an aircraft-specific simulator to provide formation practice for

UPT students. The results obtained appear to support a conclusion that trainer practice does have positive transfer to aircraft formation flying. A principal finding is that students in this experiment were influenced more by stage of training than were more advanced students in previous researach using the same equipment.

Reno, B. (1989). Full field of view dome display system. In AIAA Flight Simulation Technologies Conference and Exhibit, A Collection of Technical Papers (AIAA Paper No. 89-3316, pp. 390-394). Washington, DC: American Institute of Aeronautics and Astronautics.

The requirements for a visual system to adequately support a fighter aircraft's missions, particularly the low-level and air-to-ground scenarios, are very demanding. Present-day visual systems lack the brightness, FOV, and/or resolution to satisfy these requirements. The Full Field of View Dome Display System is an effort to address this problem by providing a display system with higher brightness and resolution than previously attained in a dome simulator over 100% of the FOV of a modern-day fighter.

Ricard, G. L., Cyrus, M. L., Cox, D. C., Templeton, T. K., & Thompson, L. C. (1978). Compensation for transport delays produced by computer image generation systems (NAVTRAEQUIPCEN-IH-297/AFHRL-TR-78-46, AD-A056 720). Orlando, FL: Naval Training Equipment Center/Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

This report describes a cooperative U.S. Navy and Air Force effort aimed at the problem of image flutter encountered when visual displays that present CGI are used for the simulation of certain flying situations. Two experiments are described that extend laboratory work on delay compensation schemes to the simulation of formation flight in a research device - the ASPT. The scheme used was one where low-pass filters were added to the lead-generation software of the visual display system. Both studies were geared to determining break-points for those filters that would allow adequate flying control performance and provide an acceptable display. These experiments were based on the notion that a trade exists between the suppression of the visual image's flutter and the removal of the low-frequency information necessary for flight control. One experiment represented a factorial combination of settings of the display filters and the nonvisual cues of aircraft motion provided by the ASPT G-seat and motion platform, and the second represented a simple comparison of filter settings. Both studies indicated that, at least for formation flight, there is a range of filter settings that will not adversely affect flight control and will adequately suppress visual flutter. This range represents half-power settings for the filters of 0.75 to 1 Hz.

Richards, W., & Dismukes, K. (1982). *Vision research for flight simulation* (AFHRL-TR-82-6, AD-A118 721). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This report is based on a workshop organized by the Committee on Vision of the National Research Council and the Air Force Human Resources Laboratory in June 1980. The workshop brought together vision scientists from academia and government scientists concerned with research on visual displays for flight simulation. The principal objective was to provide recommendations concerning fruitful approaches for the conduct of research on what visual information is needed for simulation and how it might best be presented. Low-level flight was used as a focus for discussion of problem-solving approaches. The technical report prepared by the steering group provides examples of particular research strategies that might help elucidate several of the long-range issues in visual simulation.

Rife, R. W. (1977). Level-of-detail control considerations for CIG systems. In E. G. Monroe (Ed.), *Proceedings of the 1977 IMAGE Conference* (AD-A044 582, pp. 142-159). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

CIG visual systems for flight simulators have various limitations relating to the detail of the visual scene that can be generated. The ASPT is used as this paper's example of a CIG visual system in a discussion of these limitations and techniques used to prevent these limitations from being exceeded. Definitions of key words are followed by a general description of environment preselection and a discussion pertaining to edges and edge capacities. The level-of-detail control and the overload algorithm used is explained, and some general comments pertaining to the problems involved with overload detection are given.

Rinalducci, E. J., De Maio, J., Patterson, M. J., & Brooks, R. (1983). Psychophysical assessment of simulator visual displays. In R. S. Jensen (Ed.), *Proceedings of the Second Symposium on Aviation Psychology* (pp. 489-494). Columbus, OH: Ohio State University.

The present study investigated the use of a psychophysical technique to provide a quick, low-cost evaluation of altitude cues provided by five visual display system conditions in which terrain features were varied in detail and density. Both pilot and nonpilot subjects were employed. Differences between pilots and nonpilots existed for the accuracy of altitude estimation, but the rankings of the effectiveness of the visual environments were the same for both groups. These results indicate that the use of nonpilot subjects can contribute to the overall cost effectiveness and development of future simulator displays.

Rinalducci, E. J., Martin, E. L., & Longridge, T. (1982). Visual cues in the simulation of low level flight. In J. F. Swiney, Jr. (Ed.), Proceedings of the Eighth Symposium on Psychology in the Department of Defense (ASAFA-TR-82-10, pp. 32-36). Colorado Springs, CO: Department of Behavioral Sciences and Leadership, U.S. Air Force Academy.

Visual cues used by pilots to maintain altitude in low-level flight simulation were examined. In particular, terrain texture in the form of black versus white-topped inverted cones, the presence or absence of vertical development, and the effects of rate of motion on terrain features were investigated using pilots who varied in flying experience. Less experienced pilots demonstrated increases in their mean altitude and root-mean-square deviation with an increase in airspeed or with an increase in airspeed combined with a lack of vertical development in terrain features. Experienced pilots, on the other hand, only showed increases in mean altitude and root-mean-square deviation with an increase in airspeed. No differences were found between the all black and the white-topped cones.

Rinalducci, E. J., Patterson, M. J., & De Maio, J. (1984). Static vs. dynamic presentation of visual cues in simulated low level flight. In Proceedings of the Ninth Symposium Psychology in the Department of Defense (USAFA-TR-84-2, AD-A141 043, pp. 667-671). Colorado Springs, CO: Department of Behavioral Sciences and Leadership, U.S. Air Force Academy.

The present study examined three visual display environments (i.e., a valley floor, a valley floor with walls, and a valley floor with walls and inverted pyramid terrain features) using different display presentation modes (i.e., slides, static video, and dynamic video). Both pilot and nonpilot subjects were employed. Differences between pilot and nonpilot subjects were obtained for the accuracy of altitude estimation with the former being more accurate. Although results were complex, both pilots and nonpilots showed, in general, an improvement in altitude estimation with dynamic versus static mode of presentation and with increasing complexity of the visual scene. Resolution of the display image was also shown to be an important factor. The results of this study have relevance to the development of CIG and the evaluation of the simulator visual environment.

Robinson, R. M., Thomas, M. L., Wetzel, P. A. (1989). Eye tracker development on the Fiber Optic Helmet Mounted Display. In J. T. Carollo (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1116, Helmet-Mounted Displays (pp. 102-108). Bellingham, WA: SPIE-The International Society for Optical Engineering.

Requirements necessary for successful eye tracking in aircraft simulators are covered, and two approaches to monitoring eye position are presented. An eye-position monitor for the FOHMD is described, along with two devices under development: dark-pupil and bright-pupil oculometers. Focus is placed on the investigation of saccadic suppression, eye-movement prediction, and visual acuity in a dynamic rather than static environment. In the current application of the eye-position

monitor in the FOHMD, the algorithms applied to the eye-position data correct the problems associated with eye blinks, eye tracker loss of signal, and rapid changes in pupil size. It is shown that either a dark- or a bright-pupil method of imaging the eye is reliable.

Semple, C. A., Hennessy, R. T., Sanders, M. S., Cross, B. K., Beith, B. H., McCauley, M. E. (1981). Aircrew training devices: Fidelity features (AFHRL-TR-80-36, AD-A094 665). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This report presents relationships between aircrew training requirements and aircrew training device fidelity features and degrees of fidelity. Research and operational experience information was used. Fidelity refers to the degree to which cue and response characteristics of aircrew training devices allow for the learning and practice of specific training tasks. Visual system fidelity is addressed from the standpoints of visual system physical design and training effectiveness. Platform motion systems and their relationship to training effectiveness, efficiency, and user acceptance are addressed. The design and use of force cuing devices (e.g., G-seats and arm loaders) and their relationship to platform motion and visual system cues are discussed. A conceptual training effectiveness framework is presented for use in assessing the training value of motion and force cuing. Flight characteristics fidelity, or the reproduction of aircraft control and response characteristics in an aircrew training device, is examined to determine instructional values of having an aircrew training device "feel" like its aircraft counterpart. A conceptual framework is presented to guide training decisions about the need for high flight characteristics fidelity. The interaction of visual and motion system cues is discussed in terms of effects on training and performance of delays between related cues.

Serreyn, D., & Duncan, D. (1981). Computer image generation: Advanced visual/sensor simulation (AFHRL-TP-81-23, AD-A107 098). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This study investigated, developed, and evaluated various CIG techniques to overcome the qualitative limitations of current CIG imagery produced by edge-based systems. The study concluded with an integration of techniques into a system concept. This report describes the techniques investigated, the system concept developed, and the general hardware implementations that are useful for cost/benefit tradeoffs. The system concept presented is based on the use of textured terrain for realistic simulation. The approach also involves the display of terrain as curved surfaces represented by bicubic splines.

Sisson, N., Howard, C., & Pierce, B. (1993). Prediction of light-valve color output. In J. Morreale (Ed.), 1993 SID International Symposium Digest of Technical Papers, Volume XXIV (pp. 137-140). Playa del Rey, CA: Society for Information Display.

This paper describes the results of an entire gamut polynomial fit used to predict the color output of light-valve projectors and other displays. We also discuss the temporal variability characteristics of light-valve projectors that are different from CRT and LCD displays.

Smith, J. F. (1981). Experience with flight simulators - Training effectiveness and future developments (AFHRL-TP-81-41, AD-A108 087). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

This paper was prepared at the request of the DGLR Program Committee Chairman and presented at the German Society for Aeronautics Symposium held 20-21 May 1981 in Cologne, Germany. The theme of the symposium was "Simulators for Pilot Training." As requested, the paper provides a discussion of experience in the use of simulators for pilot training in the U.S. Because of the author's background, it was further limited to U.S. Air Force utilization and related areas. The use of ground-based flight simulators in pilot training programs as alternatives to more expensive training media has been practiced at some level for over 50 years. The paper opens with a brief discussion of the very early experiences of Mr. Ed Link and his "PILOT MAKER." Progress is then summarized in three time frames. The first period, 1934-1949, spans World War II and notes the emphasis in the use of trainers in instrument and procedures training for propeller-driven aircraft. The second period, 1950-1970, covers the transition from conventional to jet aircraft simulators and the evolution of electronic devices (as opposed to bellows or manual linkage actuation). Simulator training objectives retain their focus on instruments and procedures to which are added weapon system operations. Trainers are procured for nearly all jet aircraft weapon systems. The third period, 1971-1980, includes a discussion of factors that caused increased use of simulators, a summary of major equipment modifications to increase training capabilities, and a discussion of training research activities. The final section of the paper provides the author's opinion as to future simulation applications. Three areas are discussed; the first includes comments on how we may improve utilization of existing equipment, the second provides some ideas concerning future simulator training requirements, and the third provides a broad summary of planned and needed research.

Soland, D., Voth, M., & Narendra, P. M. (1981). Real-time feasibility for generation of nonlinear textured terrain (AFHRL-TR-79-27, AD-A095 070). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This study was conducted by Honeywell for the Air Force Human Resources Laboratory in order to evaluate and study a potential new approach for the simulation of visual and sensor imagery for U.S. Air Force training applications. This report describes the hardware implementation of a curved-surface method for textured terrain imagery. General comments and

details of the algorithms are presented. This is followed by a discussion of the hardware required for a real-time implementation of this technique. The approach involves the display of terrain as curved surfaces represented by bicubic splines. Texture patterns may then be mapped to these terrain surfaces. Buildings or cultural features may be drawn using polygonal surfaces. This curved approach is of interest because it may represent a more cost-effective method to include more detail in the simulated imagery. Current systems are constrained to the use of straight edges in the representation of real-world features and require large numbers of edges to display complex, irregular objects such as terrain. Therefore, the curved-surface approach may demonstrate many advantages over the straight-edge technique.

Stenger, A. J., Zimmerlin, T. A., Thomas, J. P., & Braunstein, M. (1981). Advanced computer image generation techniques exploiting perceptual characteristics (AFHRL-TR-80-61, AD-A103 365). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The study objectives involve applying psychological knowledge of visual perception to improve real-time CIG simulators. The primary objective is to suggest and identify CIG algorithms for visual simulation that improve the training effectiveness of CIG simulators. The secondary objective is to identify areas of basic research in visual perception that have a significant impact on improving CIG technology. The project proceeded in a sequence of three phases. The first phase entailed observing existing CIG simulators. During the second phase, existing perceptual knowledge was studied in light of the capabilities and limitations of existing CIG simulators. In the third phase, improved CIG algorithms were developed, and relevant areas for further perceptual research were identified.

Stephens, C. W., Dickens, T. M., Widder, P. A., & Sheen, R. L. (1982). Red Flag simulation: Development of an interactive, high threat combat environment. In Proceedings of the 4th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 459-465). Arlington, VA: National Security Industrial Association.

Flight simulators are being used to an ever greater degree to train combat related skills. The Air Force Human Resources Laboratory has been tasked with determining the effectiveness of simulator training and provide guidance as to how to train for combat in a simulator. In order to provide these answers, high-fidelity, realistic combat simulation must be accomplished. Using the ASPT, techniques have been developed for the generation of realistic combat environment scenarios. These techniques were used to develop an environment that closely models the Tonopah Range at Nellis AFB, a range that is often used for Redflag exercises. Advanced database modeling techniques were used to create the geographical features, cultural features, and provide low-level cues utilizing the maximum capability of the ASPT image generating system. The environment had numerous threats, including SAMs and AAA. The pilot could interact with this environment in the same manner as with a real combat environment.

Stober, S., Lippay, A., McKinnon, M., Welch, B., & Longridge, T. (1983). A psychophysical evaluation of an area-of-interest (AOI) display. In Proceedings of the Nineteenth Annual Conference on Manual Control (pp. 392-399). Cambridge, MA: Massachusetts Institute of Technology.

In order to provide a low-cost, wide-FOV visual system for aircraft simulation, techniques are being developed for displaying a high-resolution AOI with a larger low-resolution FOV. One project being developed by CAE Electronics Ltd and the Human Resources Laboratory (Williams AFB) is the Helmet Mounted Display, in which an AOI is slaved to the pilots' eye movements. This paper describes psychophysical experiments that are being set up in an attempt to define the specifications for such a display system.

Thomas, M., Barrette, B., Shenker, M., & Weissman, P. (1989). The enlarged field of view fiber optic helmet mounted display. In AIAA Flight Simulation Technologies Conference and Exhibit, A Collection of Technical Papers (AIAA Paper No. 89-3319, pp. 403-408). Washington, DC: American Institute of Aeronautics and Astronautics.

The development of an enlarged-FOV FOHMD as Phase V of the FOHMD program is discussed. Two oculometers were developed to the point where eye-servoed operation can be evaluated. The eye servo range was increased to +/- 45-deg horizontally by 25-deg vertically. Continued refinements to the optical head tracker enlarged the tracking envelope to totally encapsulate an F-16 cockpit.

Thomas, M., & Geltmacher, H. (1993). Combat simulator display development. Information Display, 9(4 & 5), 23-26.

This paper describes the variety of advanced flight simulation display systems developed at the Aircrew Training Research Division of the Armstrong Laboratory. The systems are the Limited-Field-of-View Dome display, Full-Field-of-View Dome display, Display for Advanced Research and Training, Mini-Display for Advanced Research and Training, FOHMD, and low-cost helmet displays.

Thomas, M. L., Martin, E., & Serfoss, G. (1992). Low cost portable display development and evaluation for distributed interactive tactical simulators. In Proceedings of the Twelfth International Display Research Conference, Japan Display '92 (pp. 669-672). Playa del Rey, CA: Society for Information Display; Tokyo, Japan: Institute of Television Engineers of Japan.

The objective of this program was to develop and demonstrate a significantly more cost-effective display capability with the flexibility to address a variety of vehicle simulation requirements. Design goals were to present full FOV imagery, with acceptable levels of display resolution and

brightness, that can fit in an office environment, i.e., 10-ft ceilings, normal power, and ambient cooling. The tactical simulation being developed as a demonstration is intended to support training in an F-15E aircraft on a mission hunting for critical mobile targets such as SCUDS.

Thomas, M. L., & Reining, G. (1990). The Display for Advanced Research and Development: An "inexpensive" answer to tactical simulation. In ITEC, International Training Equipment Conference and Exhibition Proceedings (pp. 156-161). Warminster, Wiltshire, UK: ITEC Ltd.

The Display for Advanced Research and Training (DART) is a relatively low-cost display device for presenting out-the-window visual imagery in a flight simulator. In tandem with increasingly available low-cost IGs, the DART shows promise for achieving sufficient fidelity to provide a useful training tool for aircraft such as the F-16. The system is a rear-screen projected dodecahedron with eight channels of imagery surrounding the design eye point. The screens used are flat pentagons with a net gain of one and are abutted with gaps of about a centimeter. The projectors, BARCODATA 600s, are full-color, off-the-shelf, CRT-based devices that can easily display 1,000 lines of video. The result is wrap-around real imagery, presented about 1 m away from the design eyepoint, with a nonoptimized brightness of 7 fL. The resolution is 4.75 arc min/pixel, based on 75-deg angular subtend per window. The field of regard is approximately 300-deg horizontally by 150-deg vertically, lacking only the rear window and portions of what would be the wing area, for a complete encapsulation of imagery. A Polhemus magnetic tracker is used to track the head, and these data are used to reduce IG channel requirements. Because imagery isn't required behind the head, the appropriate projectors can be dimmed and the available IG channels used to present head-centered imagery. Contrast, even with all eight windows illuminated, has been measured at 30:1 and gets better with fewer channels illuminated.

Thomas, M. L., Reining, G., & Kelly, G. (1991). The Display for Advanced Research and Training: An "inexpensive" answer to tactical simulation. In H. M. Assenheim, R. A. Flasck, T. M. Lippert, & J. Bentz (Eds.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1456, Large-Screen-Projection, Avionic, and Helmet-Mounted Displays (pp. 65-75). Bellingham, WA: SPIE-International Society for Optical Engineering.

Realizing that the cost per channel of computerized scene generation would likely drop rapidly in the future and that the cost of visual projectors was similarly decreasing, the authors concluded that a full-FOV display, consisting of many scene generation channels and projectors, could become economically feasible. Phase I of this project was tested by installing eight rear-screen projectors on eight facets of a dodecahedron and driving it with six channels of an existing scene generator. The result was a very bright, high-contrast display that has been most pleasing to all who have seen it. Phase II development attempts to increase resolution. While the resolution obtained in Phase I is sufficient for many tasks, it is inadequate for some air-to-ground weapon delivery tasks and longer range interaction with aircraft in air-to-air engagements. Phase II adds a two-level-of-resolution, low-cost, light-weight, high-resolution helmet-mounted display. The result will be an affordable high performance display system.

Thomas, M. L., Robinson, R., Siegmund, W. P., & Antos, S. E. (1990). Fiber optic development for use on the fiber optic helmet-mounted display. Optical Engineering, 29(8), 855-862.

An FOHMD has been developed that employs large-format, coherent fiber-optic cables to satisfy U.S. Air Force full-color, high-resolution display requirements. The FOHMD cables currently used are linear multifiber arrays separated by inactive material spacers. High performance is obtained through the use of chromatic multiplexing to both improve resolution and wash out the inactive spacer structure. The achievement of still higher image quality is being sought through the use of leachable fused multifibers arrayed in a hexagonal pattern. This novel fiber-optic cable technology may furnish image transmission of the order of 10 million pixels.

Thomas, M. L., Siegmund, W. P., & Robinson, R. M. (1989). Fiber optic development for use on the Fiber Optic Helmet Mounted Display. In J. T. Carollo (Ed.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1116, Helmet-Mounted Displays (pp. 90-101). Bellingham, WA: SPIE-The International Society for Optical Engineering.

The FOHMD developed by CAE Electronics for the Air Force Human Resources Laboratory requires very-large-format, coherent fiber-optic cables. These cables must support the FOHMD's demanding MTF requirements in full color and be flexible, durable, lightweight, and up to 6-ft long. These requirements have so constrained glass technology that conventional approaches are not capable of delivering the requisite performance. It is shown that fused/leached fiber-optic cables have the potential to provide image transmission capability equal to 10 channels of the best available IGs. When coupled with chromatic enhancement to mask fixed-pattern and broken-fiber noise, the resulting MTF of the FOHMD optics would deliver a resolution equal to 1.5 arc min/pixel.

Thorpe, J. A., Varney, N. C., McFadden, R. W., LeMaster, W. D., & Short, L. H. (1978). Training effectiveness of three types of visual systems for KC-135 flight simulators (AFHRL-TR-78-16). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

The objective of this study was to determine the relative training effectiveness of three generic types of simulator visual systems for application to KC-135 Combat Crew Training School: a TV/Model Board system (TV), a Day/Night Color CIG system (Day), and a Night Only/Point Light Source CIG system (Night). This study was designed to identify any deficiencies associated with these three systems that might adversely impact training. The comparative effectiveness data for the three visual systems was generated using a transfer-of-training design. Subjects were 30 recent graduates of UPT transitioning into the copilot position of the KC-135. They were divided into three equal groups, each receiving simulator training on one of the three visual systems. Each student received up to 8 hr of instruction in the simulator (mean training time: 6.57 hr) with

instruction by U.S. Air Force Strategic Air Command KC-135 IPs scheduled over a two-day period. Following simulator training, each student flew two evaluation sorties in the KC-135 aircraft with three to four landings attempted on each sortie. All subjects demonstrated an increase in flying skill during simulator training. Comparison of group mean times in the simulator required to meet a specified proficiency criterion did not reveal any differential efficiency (i.e., time required to meet proficiency) among the three systems. A comparison of evaluation flight scores revealed that the Night and Day systems trained more effectively than the TV system. The TV system trained less effectively in the final approach glidepath segment of the landing task. No serious deficiencies were identified in the Day and Night system that might adversely affect the quality of training. Sixty percent of the simulator trained students received the "Highly Qualified" score on their checkride landings. IPs reported a generally higher skill level from the students who had received simulator training in this study.

Waag, W. L. (1981). Training effectiveness of visual and motion simulation (AFHRL-TR-79-72, AD-A094 530). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

A review of the literature concerning the training effectiveness of visual and motion simulation is presented in this report. Although there exist much pilot opinion and in-simulator performance data, their extrapolation to training effectiveness information is questioned. The present review focuses on data obtained through the application of the transfer-of-training methodology. The results are discussed in terms of study design factors, and recommendations are made wherein additional research data are needed.

Warner, H. D. (1981). Effects of reduced visual overlap and field of view on air-to-surface weapons delivery performance (UDR-TR-81-21). Dayton, OH: University of Dayton Research Institute.

A flight simulator investigation was conducted to examine the effects of reduced visual overlap and display FOV on 30-deg dive bomb performance. Three reduced visual overlap conditions (i.e., 20, 30, and 40 deg) and normal overlap were compared. The reduced visual overlap conditions were obtained by placing a cardboard baffle between the subjects' eyes. Four head-coupled display FOV conditions were compared; the respective horizontal and vertical dimensions of the FOV conditions were 80 deg by 66 deg, 90 deg by 66 deg, 100 deg by 66 deg, and 300 deg by 150 deg. Active duty F-5 IPs served as subjects. Results indicated that bombing error was not significantly influenced by either visual overlap or FOV size. Horizontal head movement was significantly related to FOV size, such that head movement decreased as FOV size was increased.

Warner, H. D. (1988). Task listing: Visually assisted and visually dependent tasks for fighter aircraft (AFHRL-TP-87-55, AD-A191 041). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

A comprehensive listing of visually dependent and visually assisted flight tasks in U.S. Air Force fighter and attack aircraft training was developed. Additionally, the list specifies whether the tasks are trained exclusively in daylight or also at night. The individual visual tasks are provided for 11 major areas of training: (a) takeoff and landing, (b) aerobatics, (c) aircraft handling maneuvers, (d) stalls, (e) basic formation, (f) navigation, (g) air refueling, (h) tactical formation, (i) air-to-air combat, (j) low-altitude maneuvers, and (k) surface attack. Practical applications of the task listing in aviation research and development are discussed.

Warner, H. D., Hubbard, D. C., & Serfoss, G. (1992). Area-of-interest display resolution and stimulus characteristics effects on visual detection thresholds (AL-TR-1991-0134, AD-A247 830). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

An investigation was conducted to examine the effects of AOI display resolution and various stimulus characteristics on visual detection thresholds using the Limited Field-of-View Dome (LFOVD) visual simulation system located at the Aircrew Training Research Division of the Armstrong Laboratory. Two levels of AOI resolution, which was defined as the width of the line spread function at 50% of the line's maximum luminance, were evaluated. The higher resolution level was 0.081-deg horizontal by 0.071-deg vertical, and the lower resolution level was 0.132-deg horizontal by 0.121-deg vertical. The stimuli consisted of computer-generated striped and plain cylinder-shaped objects. The cylinders stood upright on the simulated terrain surface, and the stripes were placed midway between the top and bottom of the cylinders and completely encircled the cylinders. Detection thresholds were determined for both the cylinder stripes and the cylinders. The analysis of the cylinder stripes indicated that the threshold detection distances were greater with the higher resolution AOI and that the detection distances generally increased as stripe size, cylinder height, and cylinder diameter increased. The IG load management parameters dictated the detection distances for the plain cylinders, except the smallest diameter cylinders.

Warner, H. D., Serfoss, G. L., Baruch, T. M., & Hubbard, D. C. (1992). Flight simulator-induced sickness and visual systems evaluation. In A. J. Aretz (Ed.), Proceedings of the Thirteenth Symposium Psychology in the Department of Defense (USAFA TR 92-2, pp. 11-15). Colorado Springs, CO: Department of Behavioral Sciences and Leadership, U.S. Air Force Academy.

This investigation was conducted to compare the incidence and severity of simulator sickness between two flight simulator visual systems and two groups of pilots. Both visual systems were found to produce an increase in simulator sickness symptomatology, and some pilots terminated the simulator sessions due to severe discomfort. Of the pilots who completed the simulator sessions,

simulator sickness symptomatology significantly increased over the sessions. There were no differences in the measures of simulator sickness between the two visual systems or groups. The pilots recovered from the adverse effects of the simulation within 30 min following the sessions.

Warner, H. D., Serfoss, G. L., Baruch, T. M., & Hubbard, D. C. (1993). Flight simulator-induced sickness and visual displays evaluation (AL/HR-TR-1993-0056, AD-A267 019). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

The objectives of this investigation were to compare the incidence and severity of simulator sickness associated with the use of two flight simulator visual systems and to evaluate the performance characteristics of the visual displays. The visual systems were the Display for Advanced Research and Training (DART) and the Limited Field-of-View Dome (LFOVD). Two groups of pilots served as subjects. One group consisted of active duty U.S. Air Force IPs. The second group was comprised of pilots who were no longer flying military aircraft. The pilots performed a series of single-ship and formation flights, and an F-16 simulated fighter aircraft was used in conjunction with both visual systems. It was observed that both visual systems induced simulator sickness symptoms, and some of the pilots were forced to prematurely terminate the flights due to severe discomfort. For the pilots who were able to complete the flights, there was a significant increase in self-reports of discomfort over time, an increase in simulator sickness symptomatology, and a decline in postural equilibrium. However, there were no differences in the incidence of simulator sickness between the two visual systems or pilot groups. The pilots recovered from the adverse effects of the simulation within 30 min following the flights. The medians of the pilots' ratings of the visual display characteristics indicated that the only problems encountered with the two visual systems were the resolution of the peripheral field and the vertical excursion limits of the high-resolution inset for the LFOVD. Flight performance data were also collected and analyzed. Significant differences in pilot performance were observed between the visual systems and pilot groups, and significant correlations were obtained between flight performance and the simulator sickness measures.

Warner, H. D., Serfoss, G. L., & Hubbard, D. C. (1993). Effects of area-of-interest display characteristics on visual search performance and head movements in simulated low-level flight (AL-TR-1993-0023, AD-A264 661). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

An investigation was conducted to evaluate the influence of AOI display characteristics on target detection performance and head movements. Two AOI display conditions were compared: a small (i.e., 26.44-deg by 21.51-deg horizontal and vertical), higher resolution AOI and a large (i.e., 40.00-deg by 30.00-deg horizontal and vertical), lower resolution AOI. The observers viewed a computer-generated visual scene consisting of three-dimensional cylinder-shaped objects placed upright on a desert-like terrain surface. Black bands were modeled on some of the cylinders, and the bands constituted the targets. Cylinders height and diameter were varied along with the position

of the banded cylinders relative to the flight path of the simulated aircraft. Both pilots and nonpilots were used as observers. Results indicate that target detection distance varied as a function of AOI condition and the height and diameter of the cylinders on which the bands were placed, but not type of observer. Both horizontal and vertical head movements were sensitive to the differences between the AOI conditions, and the vertical movements were also influenced by type of observer. We recommend that the small, higher resolution AOI be used in situations where greater target detection distance and higher image detail are required.

Warner, H. D., Serfoss, G. L., & Hubbard, D. C. (1993). Visual cue requirements for target orientation assessment in air combat simulation (AL-TR-1993-0021, AD-A262 575). Williams AFB, AZ: Aircrew Training Research Division, Armstrong Laboratory.

The primary objective of this investigation was to determine the visual cues pilots use in air-to-air combat engagements in order to specify the level of detail required for flight simulator training. Fighter pilots were presented 35-mm slide images of 1:48-scale model target aircraft, and the pilots indicated the spatial orientation of the targets and specified the visual cues they used to determine orientation. The independent variables were: target orientation, target type, target distance, pilot experience, and pilot's own aircraft type. Eleven target cues were predominantly used and the frequency of use varied as a function of target orientation, type, and distance. Orientation recognition accuracy was also evaluated and it was also influenced by target orientation, type, and distance. Differences in pilot experience and pilot's own aircraft type had little or no effect on response accuracy. When the orientations were not clearly discernible, the pilots often indicated the orientations that would most likely occur in air combat training. Additionally, the pilots often specified the illusory reverse target orientation.

Warner, H. D., Serfoss, G. L., & Hubbard, D. C. (1994). Altitude cuing effectiveness of terrain texture characteristics in simulated low-altitude flight (AL/HR-TR-1994-0168). Mesa, AZ: Aircrew Training Research Division, Armstrong Laboratory.

Two experiments were conducted to determine the altitude cuing effectiveness of various terrain texture characteristics in simulated low-altitude flight. In Experiment 1, we compared the effects of five different texture conditions, two types of subjects (pilots versus nonpilots), and direction of altitude change (ascent versus descent) on altitude change discriminability. Results indicated that performance varied significantly as a function of texture, pilots were more sensitive than nonpilots to changes in altitude, and simulated descents were easier to discriminate than ascents. Experiment 2 involved an investigation of the effects of four of the five texture conditions previously used, direction of altitude change, and two levels of texture contrast that simulated normal daytime and dawn/dusk lighting on the detection of change in altitude. We again observed that descents were more discriminable than ascents, but unlike the first experiment, performance did not vary as a function of texture. Further, simulated dawn/dusk terrain lighting did not adversely affect performance.

Waters, B. K., Grunzke, P. M., Irish, P. A., III, & Fuller, J. H., Jr. (1976). Preliminary investigation of motion, visual and G-seat effects in the Advanced Simulator for Undergraduate Pilot Training (ASUPT). In AIAA Visual and Motion Simulation Conference. Washington, DC: American Institute of Aeronautics and Astronautics.

This study evaluated motion, FOV, and G-seat factors in ASUPT under varying environmental conditions. Five maneuvers were flown by three experienced T-37 IPs. Each subject flew 72 takeoffs, ground controlled approaches (GCAs) and landings, and 360-deg overhead traffic pattern and landings plus 27 slow flights and aileron rolls. Sixty-three dependent variables were measured using automated performance measurement on both system outputs and pilot inputs. System performance was significantly better with no motion versus either three-DOF or six-DOF motion. Pilot inputs were significantly smoother under no-motion conditions. Performance under a 150-deg by 300-deg FOV was significantly better than under a 36-deg by 48-deg FOV. The G-seat improved performance consistently, particularly under the limited FOV. Significant first order interactions emerged between FOV and G-seat factors with the G-seat most beneficial to system output measures when the limited FOV was present.

Welch, B. L., & Kruk, R. (1986). Engineering and human visual considerations in development of a fibre optic helmet mounted display. In Advances in Flight Simulation - Visual and Motion Systems, International Conference Proceedings (pp. 295-313). London, England: Royal Aeronautical Society.

The design requirements and development of an FOHMD are described. The FOHMD is applicable in ground-based and airborne operational and training devices. Methods for developing a helmet display that has a FOV of 100-deg horizontal by 60-deg vertical with separate eyepieces that have an overlap of 25 to 40 deg and a resolution of about 1 arc min/pixel are discussed. The FOV and resolution requirements determine the hardware characteristics. Luminance levels close to normal daylight levels are determined by combining optical characteristics of display devices, relay optics between display and fiber optic cables, the transmission of fiber optic cables, and the transmission of helmet optics. Various devices for the color CRTs are examined. Consideration is given to factors that affect performance: exit pupil, image stability, and eye tracking of the FOHMD.

Welch, B., & Shenker, M. (1984) . The Fiber-Optic Helmet-Mounted Display. In E. G. Monroe (Ed.), Proceedings of the 1984 IMAGE III Conference (AFHRL-TR-84-36, AD-A148 636, pp. 345-361). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

The feasibility of the FOHMD concept has been demonstrated on a breadboard system installed on a simulator at the Air Force Human Resources Laboratory. Behavioral and engineering evaluations were conducted to determine the optimum design specification for an engineering prototype scheduled for completion in late 1984. This paper describes the significant engineering aspects of the FOHMD together with the exploratory program for improving its performance.

Wetzel, P. A., Thomas, M. L., & Williams, T. T. (1990). Development and evaluation of eye tracker performance for use with the Fiber Optic Helmet Mounted Display. In Proceedings of the 12th Interservice/Industry Training Systems Conference (pp. 273-280). Arlington, VA: National Security Industrial Association.

To quantitatively evaluate the performance of eye-tracking systems for use with the FOHMD, eye-movement experiments were conducted in both the laboratory and in the helmet and the results were compared. Experimental methods for evaluation of an eye-tracker system are described and data are presented that characterize the present performance of the eye-tracker system.

Wetzel, P. A., Thomas, M. L., & Williams, T. T. (1990). Evaluation of eye tracking measurement systems for use with the Fiber Optic Helmet Mounted Display. In H. M. Assenheim & H. H. Bell (Eds.), Proceedings of SPIE-The International Society for Optical Engineering, Volume 1289, Cockpit Displays and Visual Simulation (pp. 163-174). Bellingham, WA: SPIE-The International Society for Optical Engineering.

The FOHMD projects high- and low-resolution CGI via fiber-optic bundles through collimated helmet-mounted optics to each eye. Combined head- and eye-position information is then used to position a high-resolution AOI within the head-tracked, low-resolution background. Methods for evaluation of the eye tracker are described, and experimental results presented that reveal its present performance characteristics.

Whyte, I., & Zepf, A. W. (1982). Wide-angle, multiviewer, infinity display system (AFHRL-TR-81-27(I), AD-A116 308). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This study examined the design specification for a wide-angle infinity display system with minimal distortion, convergence, dipvergence, and collimation errors for use on wide-body-aircraft simulators. The report includes a recommended final design specification; a survey of potential fabrication technologies for projector, screen, and large mirrors; an approach to fabrication of a large display system; and, finally, assembly and alignment techniques of mirror segments for a large display. (Note: Dipvergence refers to vertical movement of eyes up and down as opposed to side to side.)

Widder, P. A., & Stephens, C. W. (1983). Data base generation: Improving the state-of-the-art. In Proceedings of the 5th Interservice/Industry Training Equipment Conference (Vol. 1, pp. 164-170). Arlington, VA: American Defense Preparedness Association.

The development of databases for CIG systems is a time-consuming, labor-intensive process. While the last 10 years have seen tremendous advances in the capabilities and capacities of CIG, comparable advances have not occurred in the area of database management. As visual systems can

output more scene detail, they require databases that contain more information and, so, take longer to build. If some effort is not made to develop methods to build databases more efficiently, the limiting factor for the amount of detail contained in an environment will be the database development time. This paper discusses two projects underway at the Air Force Human Resource Laboratory, which enable databases to be developed much quicker by allowing the modelers to utilize work that has been done in the past. The first project is the development of software to convert databases formatted for one visual system to the format required for another visual system. The second project is the development of a library of models.

Wiekhorst, L. A., & Vaccaro, F. T. (1988). Flight simulator: Field of view utilized in performing tactical maneuvers (AFHRL-TP-87-50, AD-A192 412). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This paper documents the FOV utilized by experienced fighter pilots when performing specified portions of air-to-air and air-to-ground maneuvers. The FOV measurements were taken in the SAAC and the ASPT. During the air-to-ground data collection, measurements were also taken while subjects performed the same tasks with a limited FOV. Results of data collected indicate that the FOV utilized varied widely between air-to-air and air-to-ground maneuvers. In nearly all cases, the FOV utilized for air-to-air maneuvers was symmetrical and that for air-to-ground maneuvers was skewed to one side. When air-to-ground tasks were performed in a limited FOV, significantly poorer bomb scores and significantly higher release altitudes were found when compared to wide-FOV performance. A noticeable performance change in the limited-FOV condition was a tendency for pilots to turn tighter into the target. The true effect of this change in flight path still needs to be investigated. Specifying one optimal limited FOV for all maneuvers to be performed or trained in an operational flight simulator would be difficult if both cost and performance were to be considered. The variability of the FOV leads to the conclusion that placement of limited FOV will be an important decision when considering what tasks will be performed. Full training implications cannot be determined until further transfer-of-training experiments are completed.

Williams, T., Komoda, M., & Zeevi, J. (1987). Eyetracking with the fiber optic helmet mounted display. In J. Q. B. Chou (Ed.), Proceedings of the 1987 Summer Computer Simulation Conference (pp. 730-734). San Diego, CA: Society for Computer Simulation.

CAE Electronics has developed an FOHMD that includes a high-resolution inset slaved to the users point of gaze. The FOHMD is a bright, full-color, high-resolution display that allows a wide FOV. CGI is relayed to helmet-mounted optics via fiber-optic cables. Eye and head positions are monitored and used to control the display. The system's FOV is 127-deg horizontally by 66-deg vertically. The area of binocular overlap is 38 deg. A high-resolution inset field 25 deg by 18.75 deg in size can be repositioned within the FOV within 30 deg of center horizontally and 20 deg from center vertically. The position of the high-resolution inset is controlled by the user's eye position; as the eye rotates, the inset is moved such that the alignment between the center of the inset and the center of the user's visual field is maintained. The authors discuss methods used to monitor eye position in the FOHMD and the techniques and strategies used to reposition the high-resolution inset.

Williams, T., Komoda, M., & Zeevi, J. (1987). Techniques and methods used in eye-tracking in the Fiber-Optic Helmet-Mounted Display. In E. G. Monroe (Ed.), Proceedings of the 1987 IMAGE IV Conference (pp. 314-319). Tempe, AZ: IMAGE Society, Inc.

The breadboard fixed-insert FOHMD, and future plans for the engineering prototype, were described at the IMAGE III Conference. This paper examines one of the significant improvements to the FOHMD: the addition of an eye-slaved, high-resolution inset. The eye-position monitor designed specifically for this purpose is described and the strategies used to slave the high-resolution inset to point of gaze. Methods used to calibrate the eye-position monitor and detect the beginning of a saccade during data acquisition are also described, as well as the eye-movement research facility and the test apparatus developed in house.

Woodruff, R. R. (1979). Effects of varying visual display characteristics of the T-4G, a T-37 flight simulator (AFHRL-TR-79-17, AD-A071 410). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Two experiments were conducted using the T-4G, a T-37 flight simulator, to investigate the benefit to simulation of visual displays that have color or are collimated. Thirty-two U.S. Air Force undergraduate pilots learned approach and landing in the T-4G using either black-and-white or colored imagery. Thirty-eight IPs performed approach and landing with visual displays that had collimation or reduced collimation. No statistically significant differences were found in either experiment. Power analysis shows that each of these experiments would have detected a practically significant difference, if one existed, with a probability of more than 0.75. There are no psychophysical reasons to use either color or collimation. User acceptance is another thing, and if color and collimation improve acceptance, they should be used.

Woodruff, R. R., Hubbard, D. C., & Shaw, A. (1985). Advanced Simulator for Pilot Training and helmet-mounted visual display configuration comparisons (AFHRL-TR-84-65, AD-A155 326). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

This effort compared five flight simulator visual display configurations using a simulated aerial refueling task. The configurations were: (a) a helmet-mounted stereoscopic display with a 40-deg FOV, (b) a helmet-mounted biocular display with a 40-deg FOV, (c) the full ASPT 300-deg FOV, (d) the ASPT visual display masked to present a 40-deg FOV, and (e) lead lanthanum zirconate titanate stereoscopic goggles using one ASPT window. Performance of pilots using the different display configurations was observed. Results indicated horizontal position was maintained better with the wide-FOV ASPT display and boom movement was minimized with stereoscopic display.

Woodruff, R. R., Hubbard, D. C., & Shaw, A. (1986). Comparison of helmet-mounted visual displays for flight simulation. Displays Technology and Applications, 7(4), 179-185.

The objective was to determine if there are performance differences among pilots accomplishing simulated aerial refueling using five different visual displays in the A-10 cockpit of the ASPT. The

configurations were (a) a helmet-mounted binocular display, (b) lead lanthanum zirconate titanate (PLZT) goggles (binocular) used with one channel of the ASPT display, (c) a helmet-mounted biocular display, (d) the ASPT 300-deg FOV dodecahedron display, and (e) the ASPT display masked to present an FOV equal to that of the helmet-mounted displays. Forty subjects participated in this effort, eight per display condition. After an initial practice period, the subject's first task was to estimate distances behind the refueling tanker while the A-10 was flown automatically to the contact position. The pilots then flew the refueling task three times. Dependent variables measured were oscillation of the A-10 receiver receptacle around the center point of acceptable refueling boom movement envelope in three dimensions. Results show that the subject's ability to estimate distance does not differ significantly among the display configurations.

Woodruff, R. R., Longridge, T. M., Jr., Irish, P. A., III, & Jeffreys, R. T. (1979). Pilot performance in simulated aerial refueling as a function of tanker model complexity and visual display field-of-view (AFHRL-TR-78-98, AD-A070 231). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

This research was conducted in the ASPT to determine CIG complexity and FOV requirements for aerial refueling. Adequacy of three detail levels and five FOVs was assessed. Aircraft simulated, in addition to the KC-135 tanker, were the A-10, F-4, B-52, and F/FB-111. Twelve experienced pilots, three per aircraft, served as subjects. Performance measures included elapsed time to criterion, number of disconnects, and aircraft control profile. An assessment of FOV position employed for takeoff/landing versus aerial refueling was made. A-10 and F-4 pilots found the visual FOV position employed for simulated takeoff/landing must be raised approximately 12 deg to accomplish aerial refueling. B-52 and F-111 pilots found aerial refueling could be satisfactorily performed using the same FOV position employed for takeoff/landing. Performance measures indicated aerial refueling performance varied as a function of both FOV size and tanker detail level: the larger the FOV, the better the performance. Similarly, the more detailed the tanker model, the better the performance.

Zeevi, Y. Y., Porat, M., & Geri, G. A. (1990). Computer image generation for flight simulators: The Gabor approach. Visual Computer, 6(2), 93-105.

A formalism for image represemtation in combined frequency-position space is presented using the generalized Gabor approach. This approach uses elementary functions to which the human visual system is particularly sensitive and that are efficient for analysis and synthesis of visual imagery. The formalism is compatible with the implementation of a variable-resolution system wherein image information is nonuniformly distributed across the visual field in accordance with the human visual system's ability to process it. When used with a gaze-slaved visual display system, imagery generated using techniques described affords a combination of high resolution and wide FOV. This combination is particularly important in high-fidelity, computer-generated visual environments, for instance, as required in flight simulators.

APPENDIX

ABBREVIATIONS

AAA	Antiaircraft artillery
AFHRL/FT	Air Force Human Resources Laboratory, Flying Training Division
AFHRL/OT	Air Force Human Resources Laboratory, Operations Training Division
AOI	Area of interest
ASPT	Advanced Simulator for Pilot Training
ASUPT	Advanced Simulator for Undergraduate Pilot Training
CGI	Computer-generated imagery
CIG	Computer-image generation
CRT	Cathode ray tube
DART	Display for Advanced Research and Training
DOF	Degrees of freedom
FAC	Forward air control
FOHMD	Fiber-Optic Helmet-Mounted Display
FOV	Field of view
IG	Image generator
IP	Instructor pilot
IR	Infrared
LCD	Liquid crystal display
MTF	Modulation transfer function
SAM	Surface-to-air missile
SAAC	Simulator for Air-to-Air Combat
TV	Television
UPT	Undergraduate pilot training
WST	Weapons Systems Trainer

AUTHOR INDEX